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Harper

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(54) **UTILIZATION OF MULTIPLE WRITER MODULES FOR SIMULTANEOUSLY WRITING TWO TIMES THE NUMBER OF DATA TRACKS IN A COMPACT FORM FACTOR**

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(51) **Int. Cl.**

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G11B 5/008	(2006.01)
G11B 5/29	(2006.01)
G11B 5/55	(2006.01)

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CPC ***G11B 5/56*** (2013.01); ***G11B 5/00813*** (2013.01); ***G11B 5/29*** (2013.01); ***G11B 5/5504*** (2013.01)

(58) **Field of Classification Search**
CPC G11B 5/29; G11B 5/5504; G11B 5/56
USPC 360/261.1, 291, 121
See application file for complete search history.

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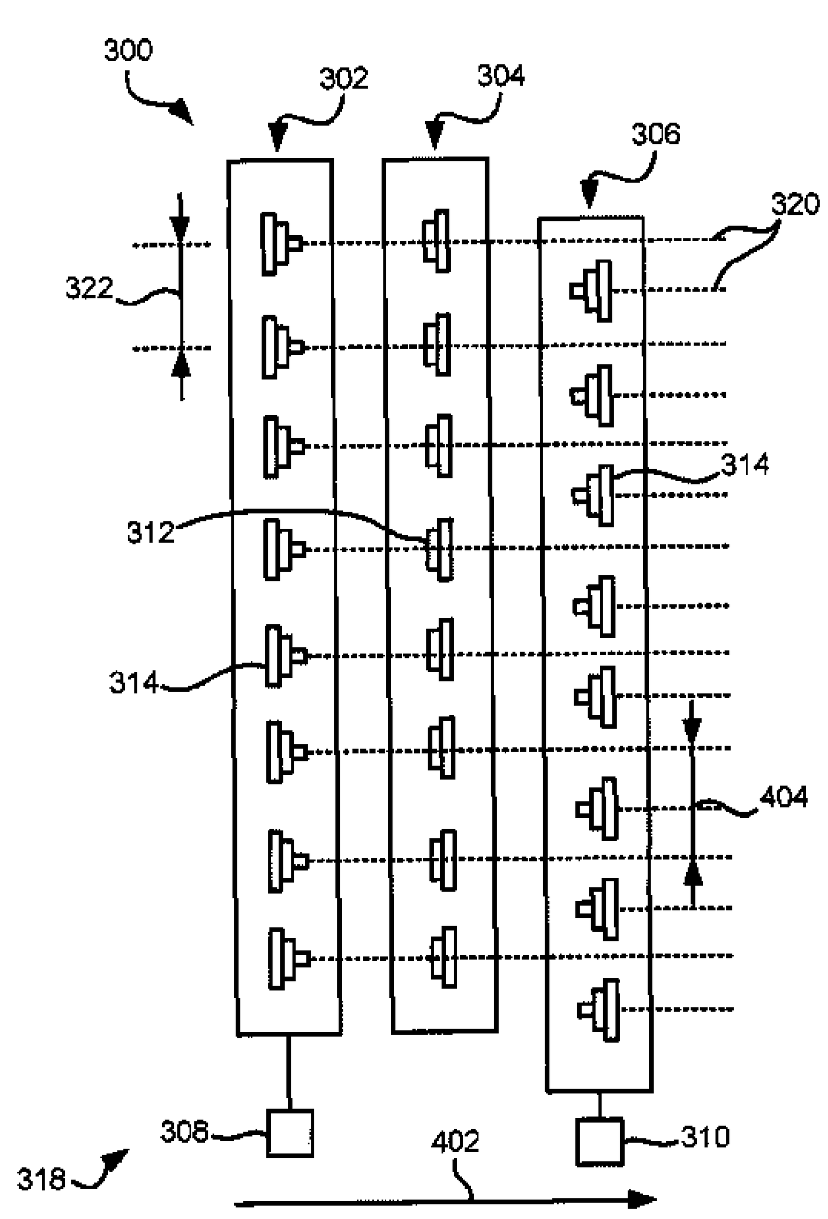
(57) **ABSTRACT**

In one general embodiment, an apparatus includes a first outer module having an array of writers, a second outer module having an array of writers, an inner module positioned between the outer modules, and a first actuator for shifting the first outer module. The shifting is relative to the inner module, in a cross-track direction by about one half of a center-to-center pitch of the writers of the first outer module. The inner module has an array of readers.

19 Claims, 12 Drawing Sheets



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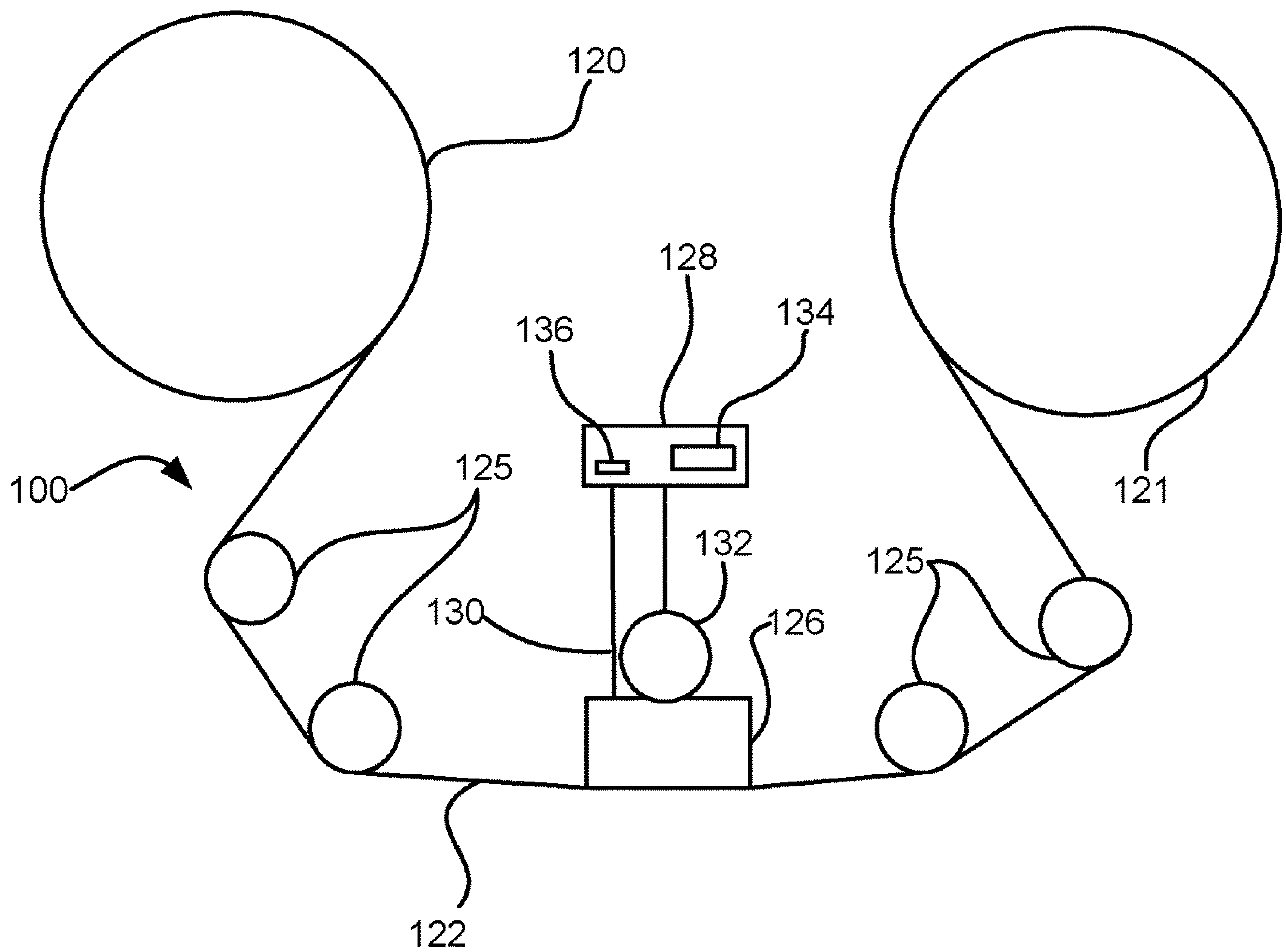
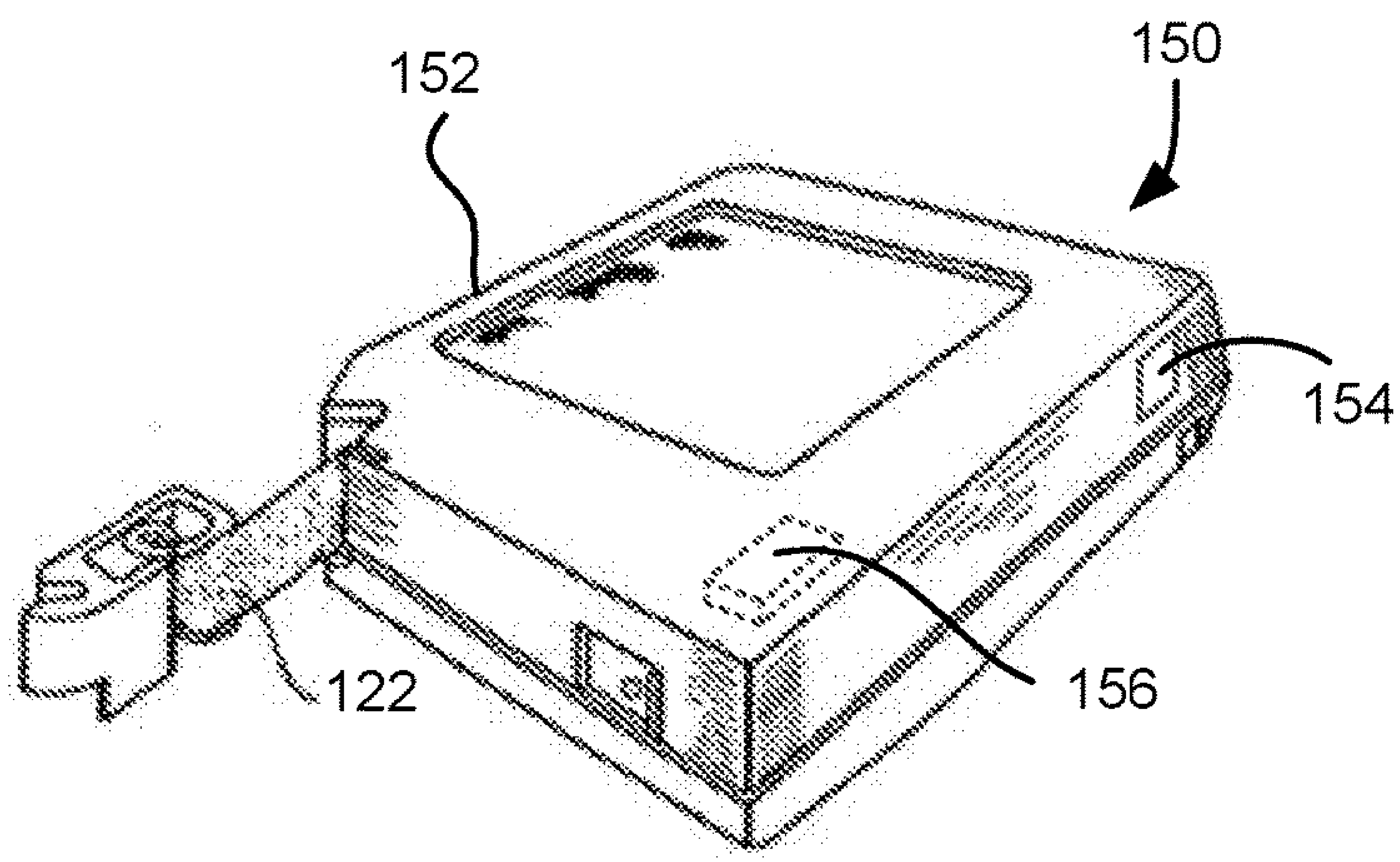


120
128
136
134
100
125
121
132
125
130
126
122

FIG. 1A



152
150
154
156
122

FIG. 1B

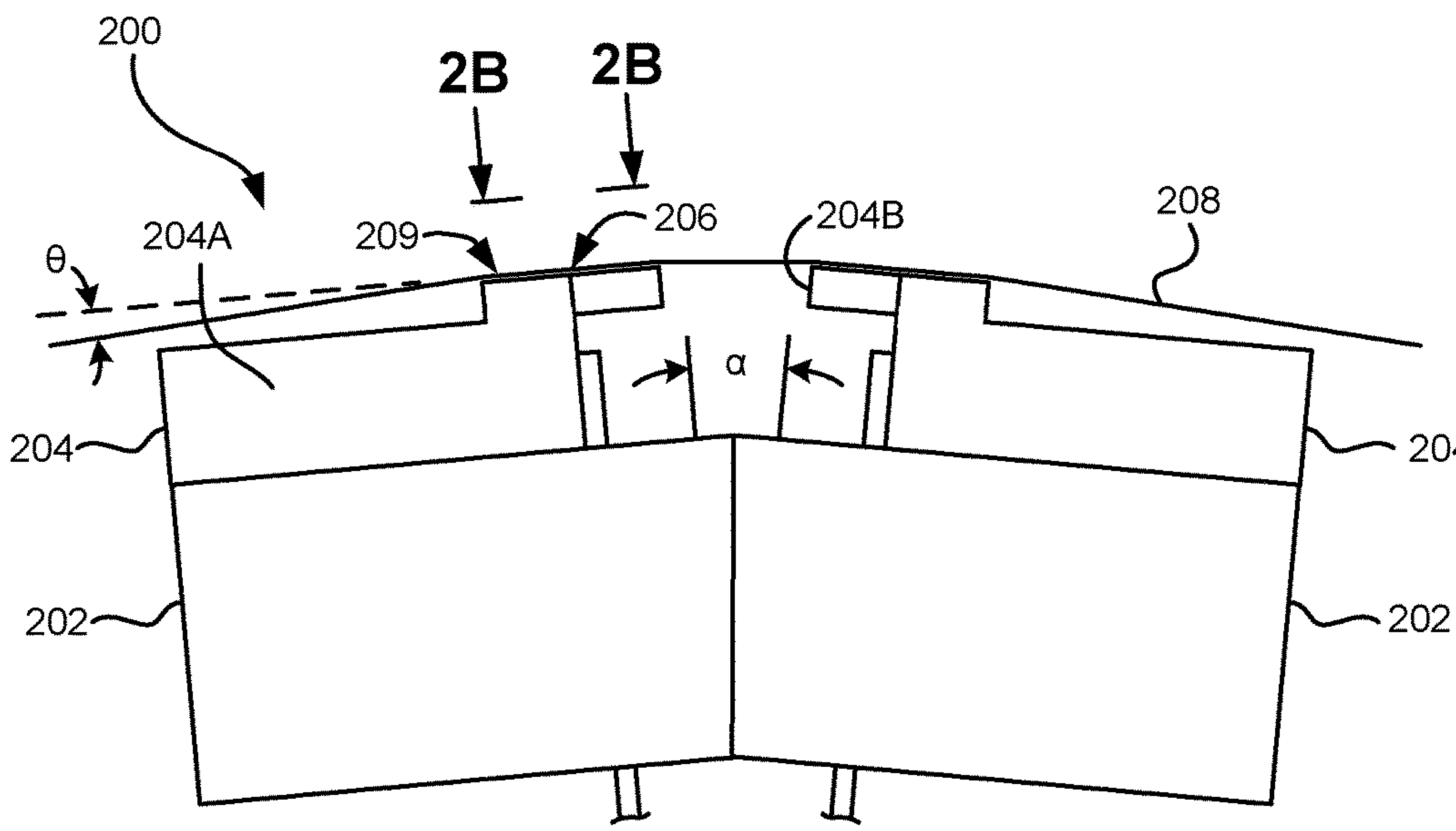

200
2B
2B
θ
204A
209
206
204B
208
α
204
204
202
202

FIG. 2A

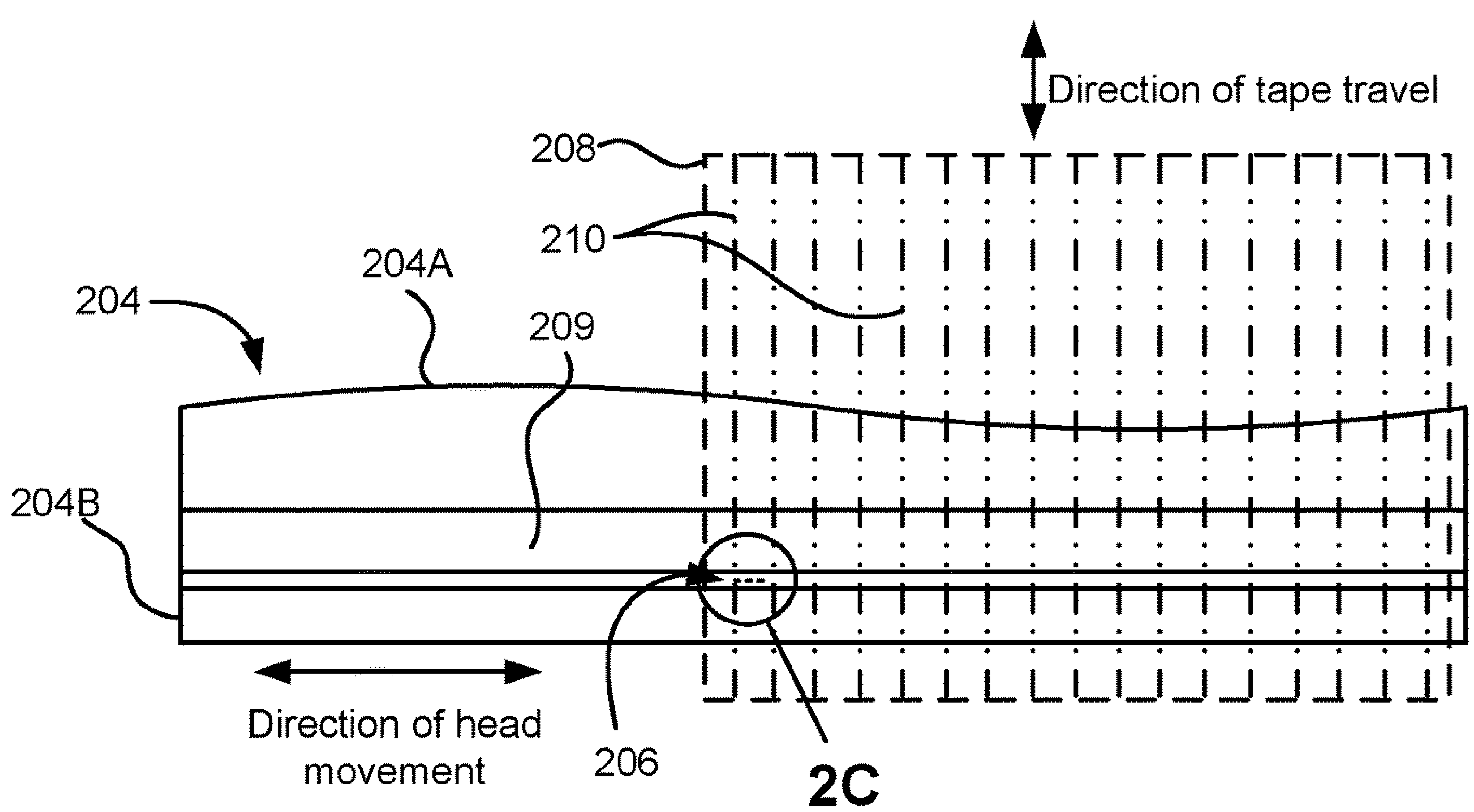

Direction of tape travel
208
210
204A
204
209
204B
Direction of head movement
206
2C

FIG. 2B

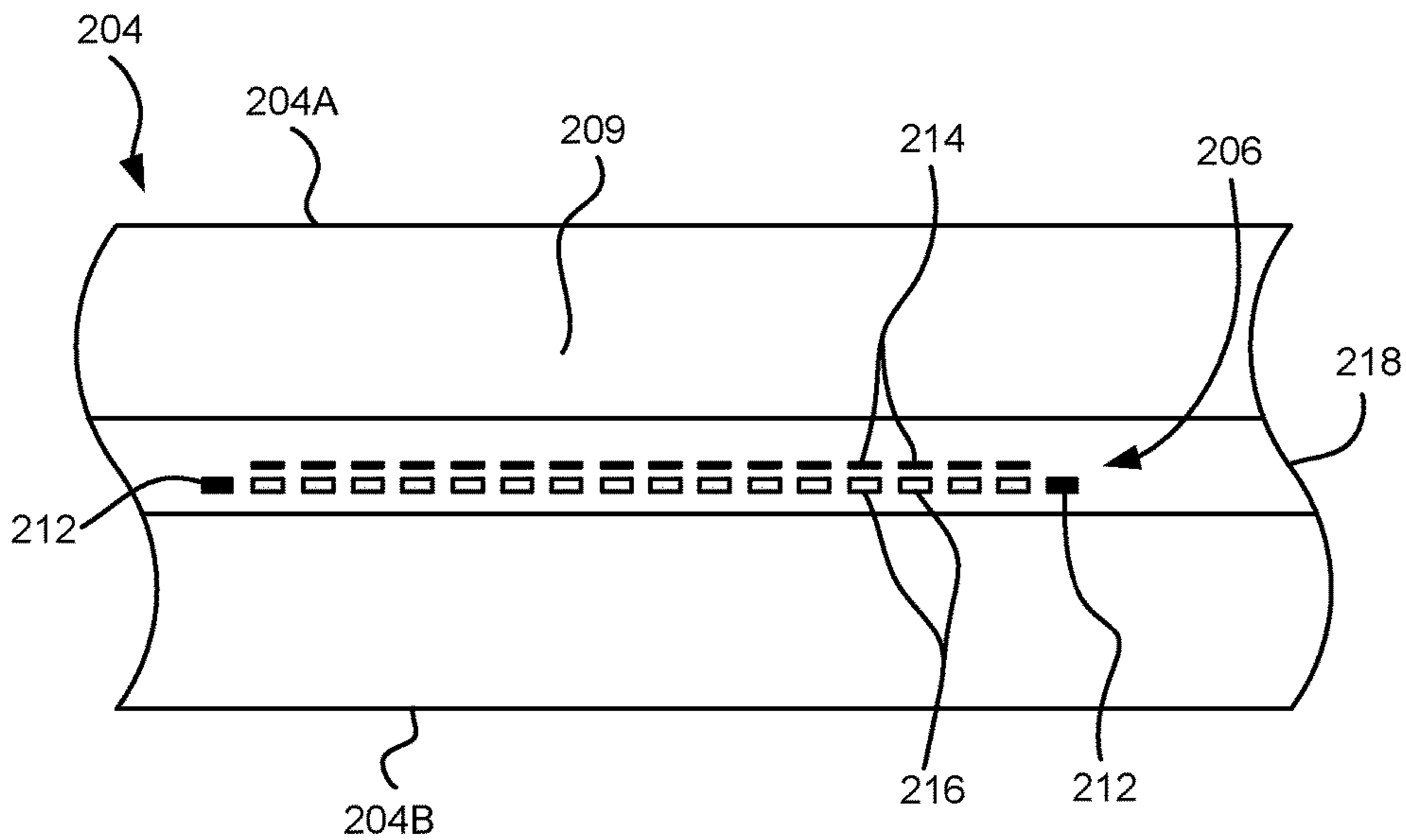

204
204A
209
214
206
218
212
216
212
204B

FIG. 2C

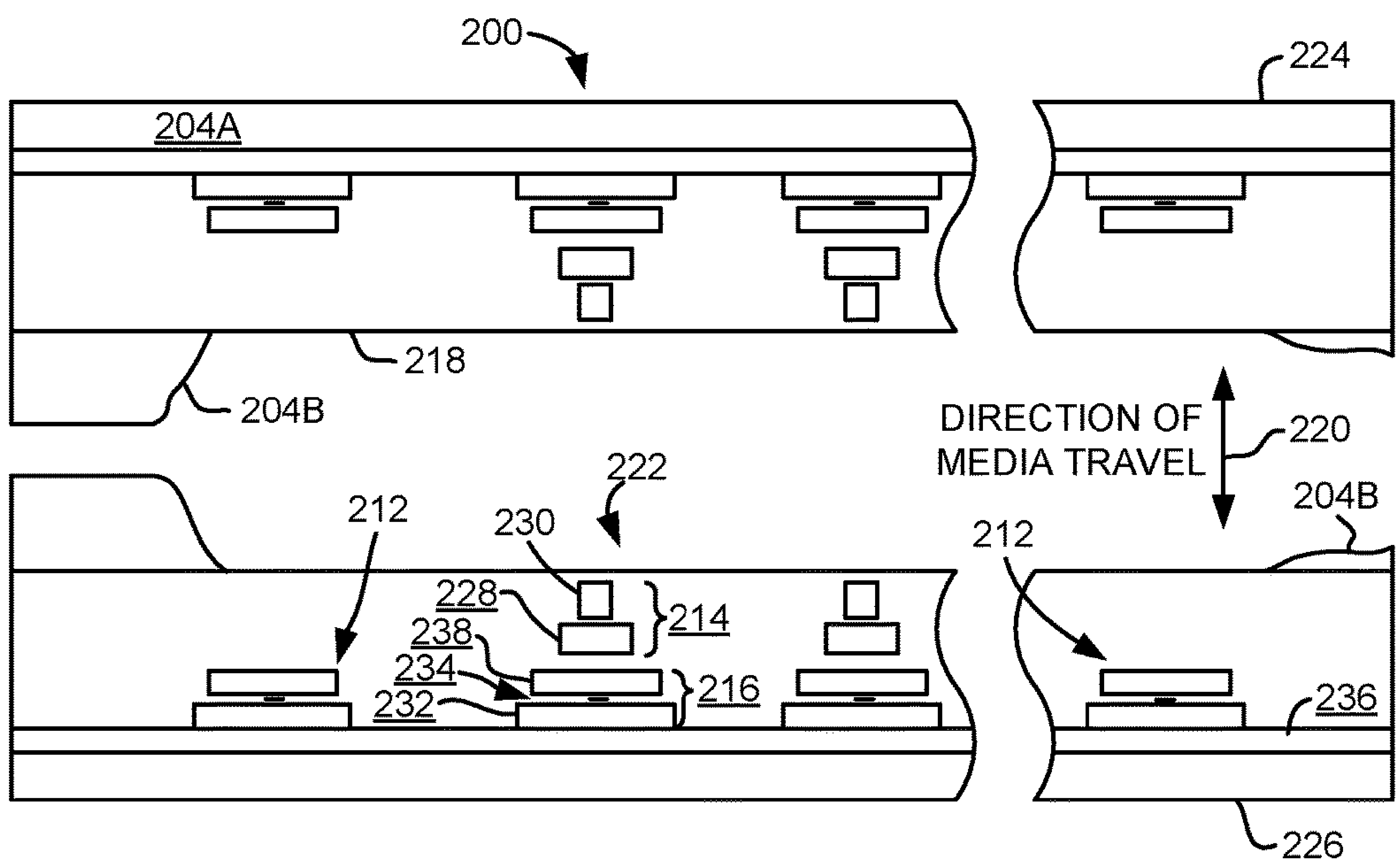
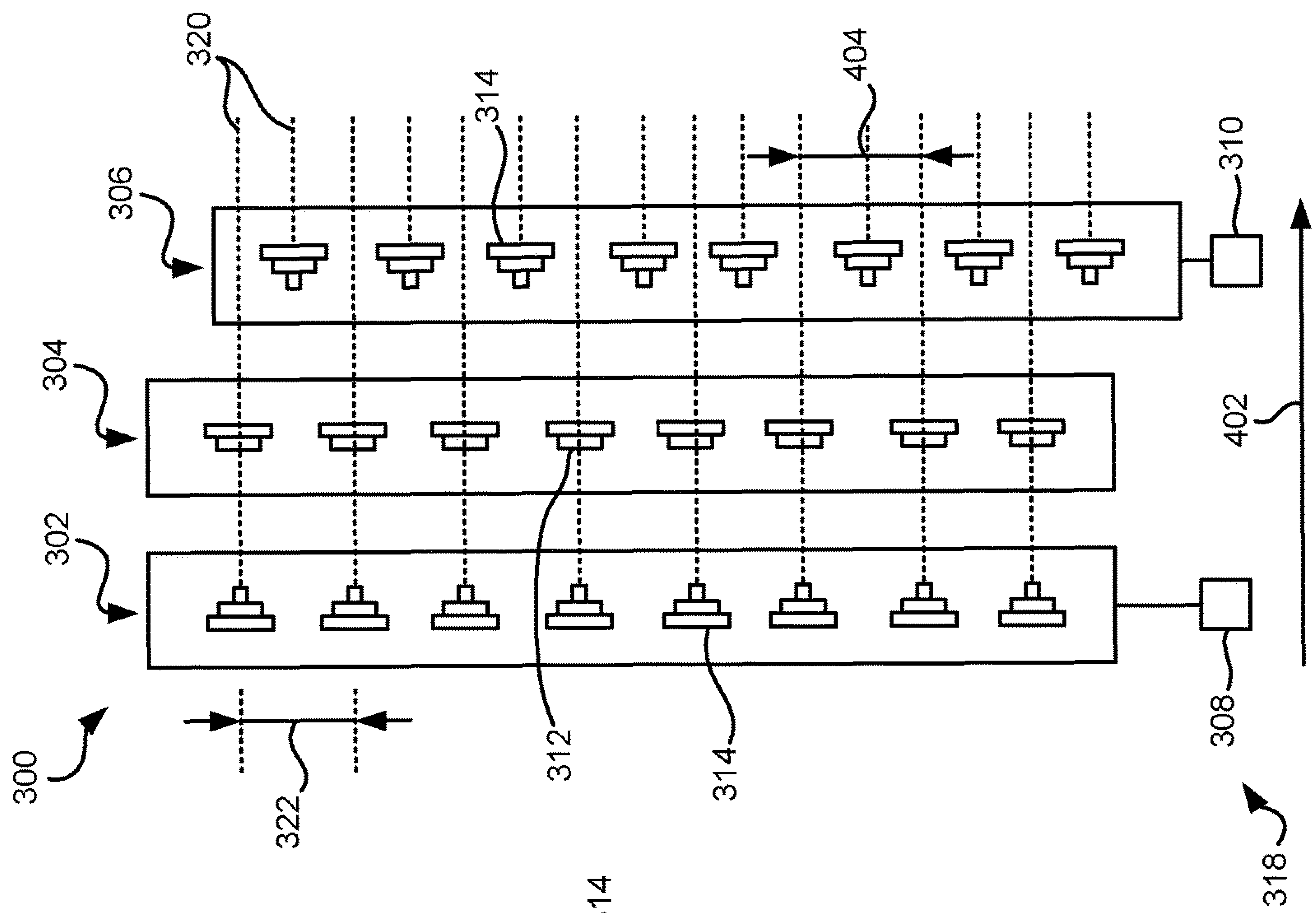

200
224
204A
218
204B
DIRECTION OF
MEDIA TRAVEL
220
222
212
230
204B
212
228
214
238
234
216
232
236
226

FIG. 2D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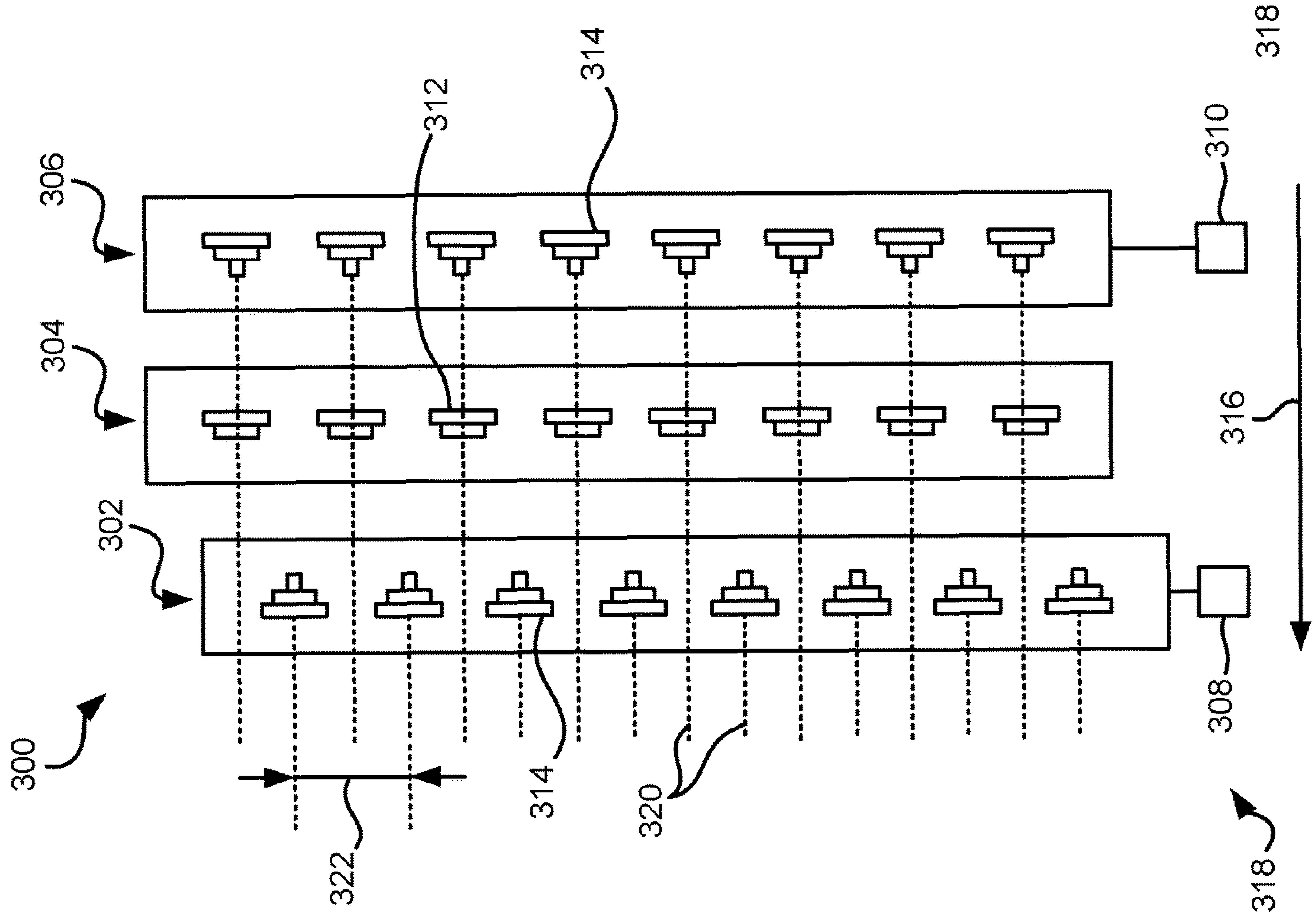
302
304
306
308
310
312
314
314
318
320
322
402
404

FIG. 4


300
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306
308
310
312
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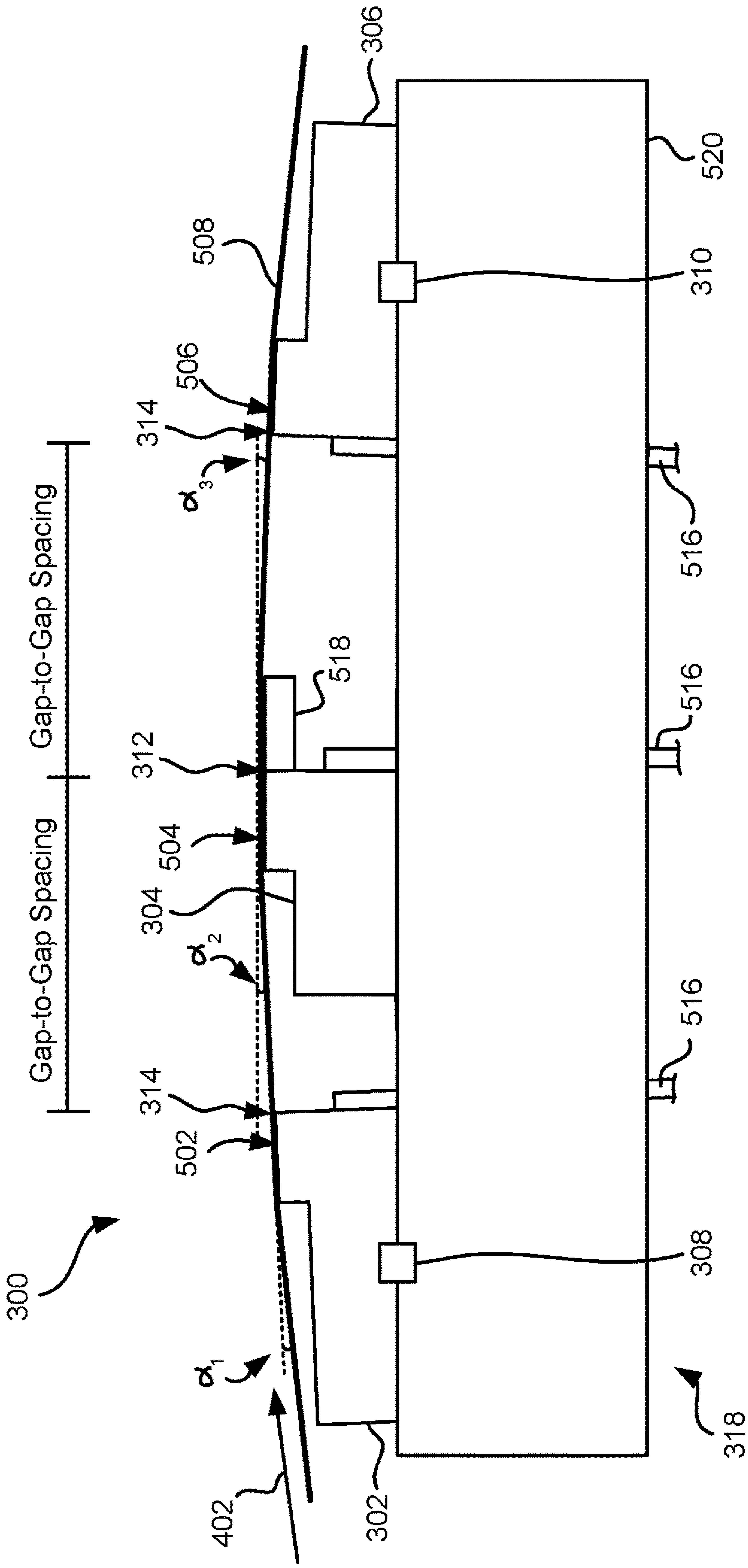
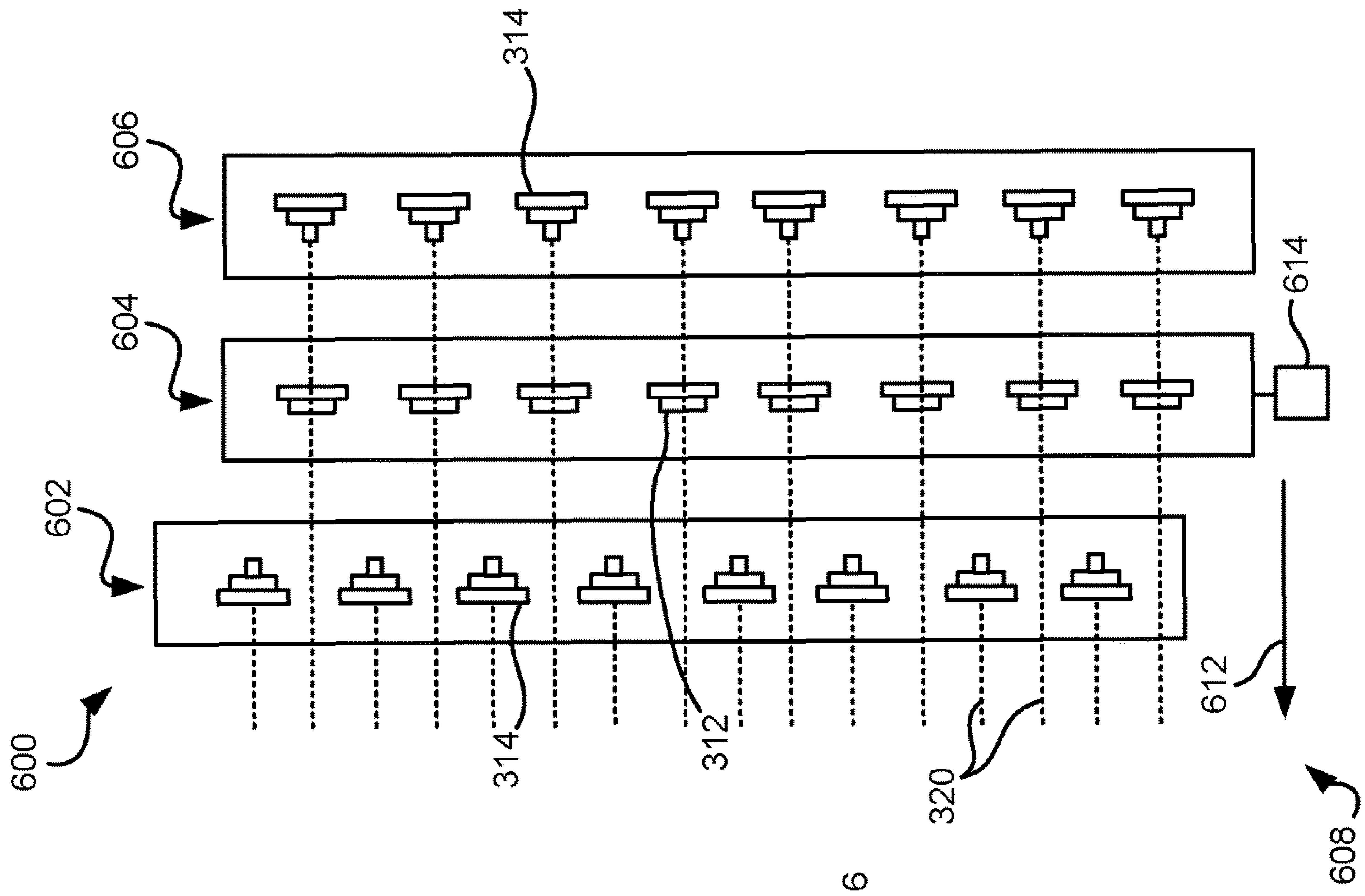
316
318
320
322

FIG. 3



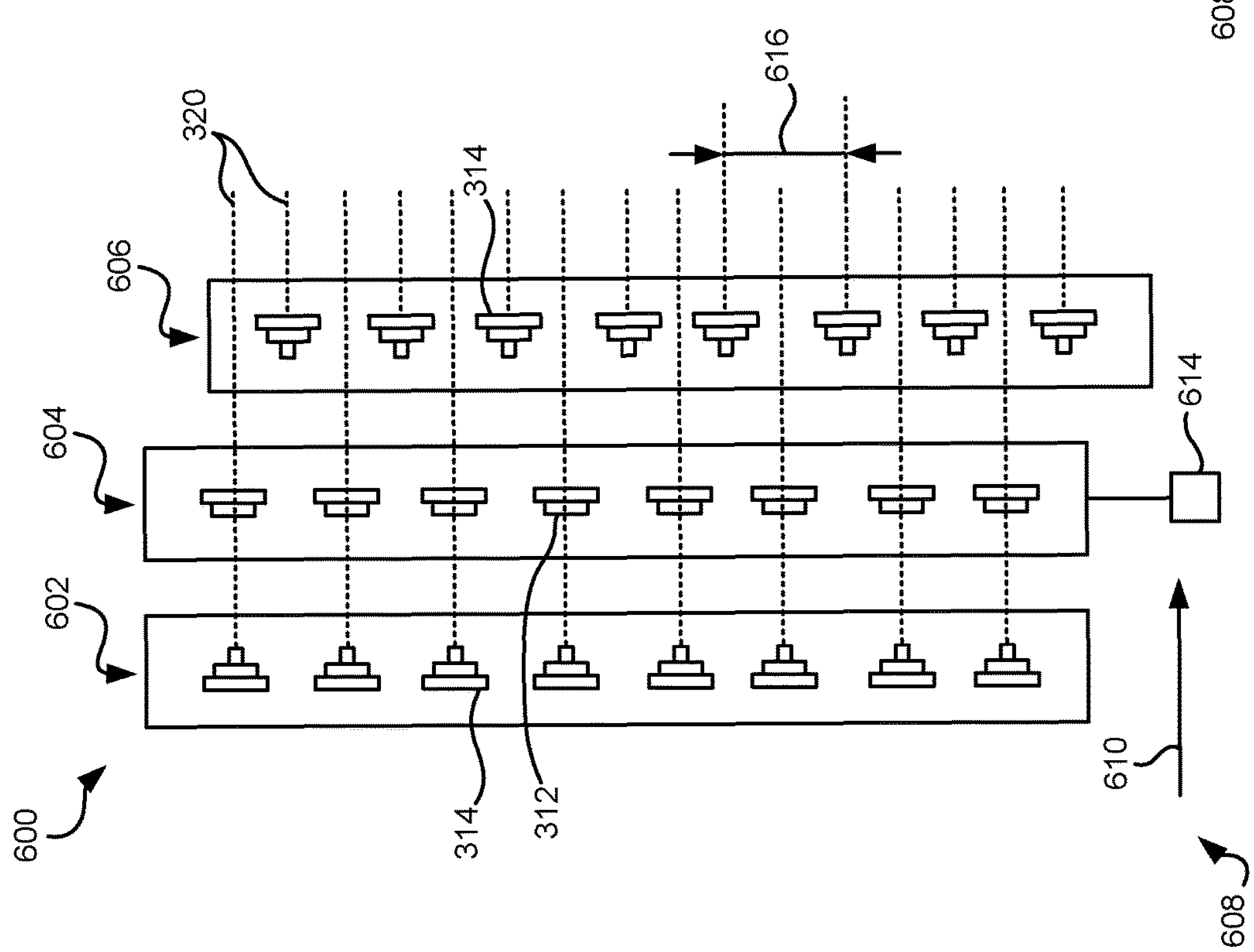
300
302
304
306
308
310
312
314
314
318
402
502
504
506
508
516
516
516
518
520
Gap-to-Gap Spacing
Gap-to-Gap Spacing
α_1
α_2
α_3

FIG. 5



600
602
604
606
314
314
312
320
612
614
608

FIG. 6B



600
602
604
606
314
314
312
320
616
610
614
608

FIG. 6A

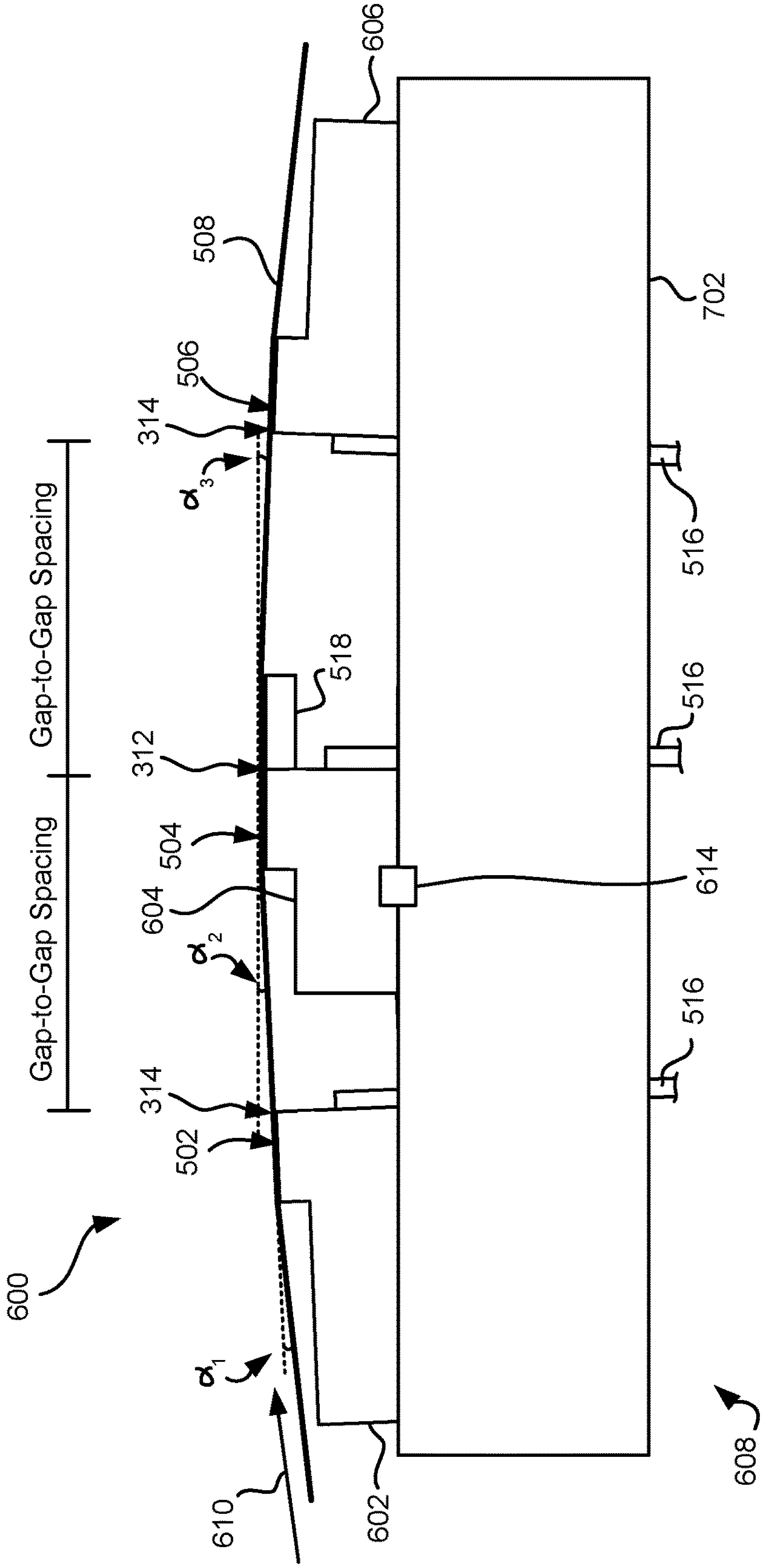

606
508
702
506
314
Gap-to-Gap Spacing
518
516
516
312
504
614
604
Gap-to-Gap Spacing
516
314
502
600
602
610
608

FIG. 7

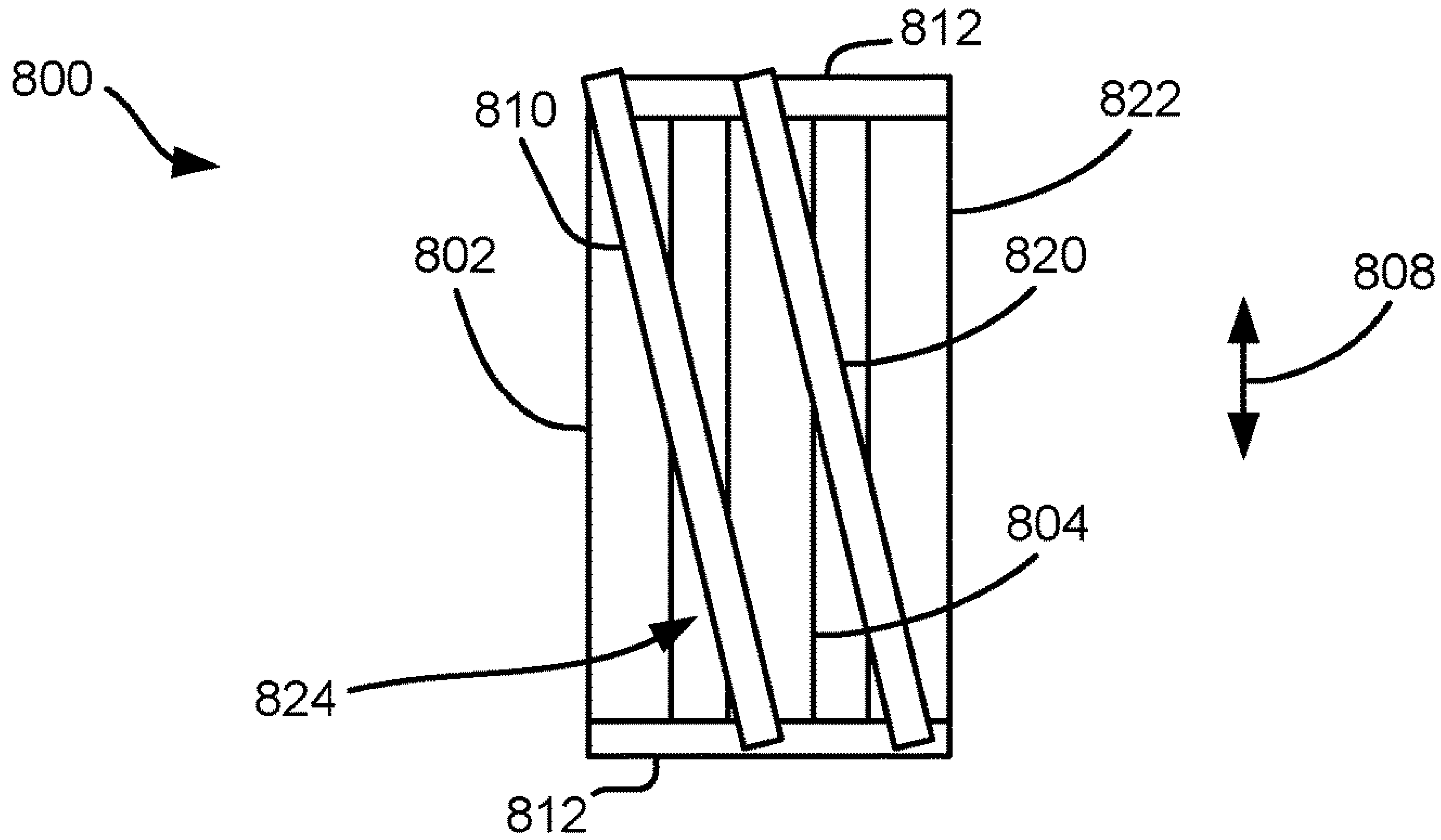


FIG. 8

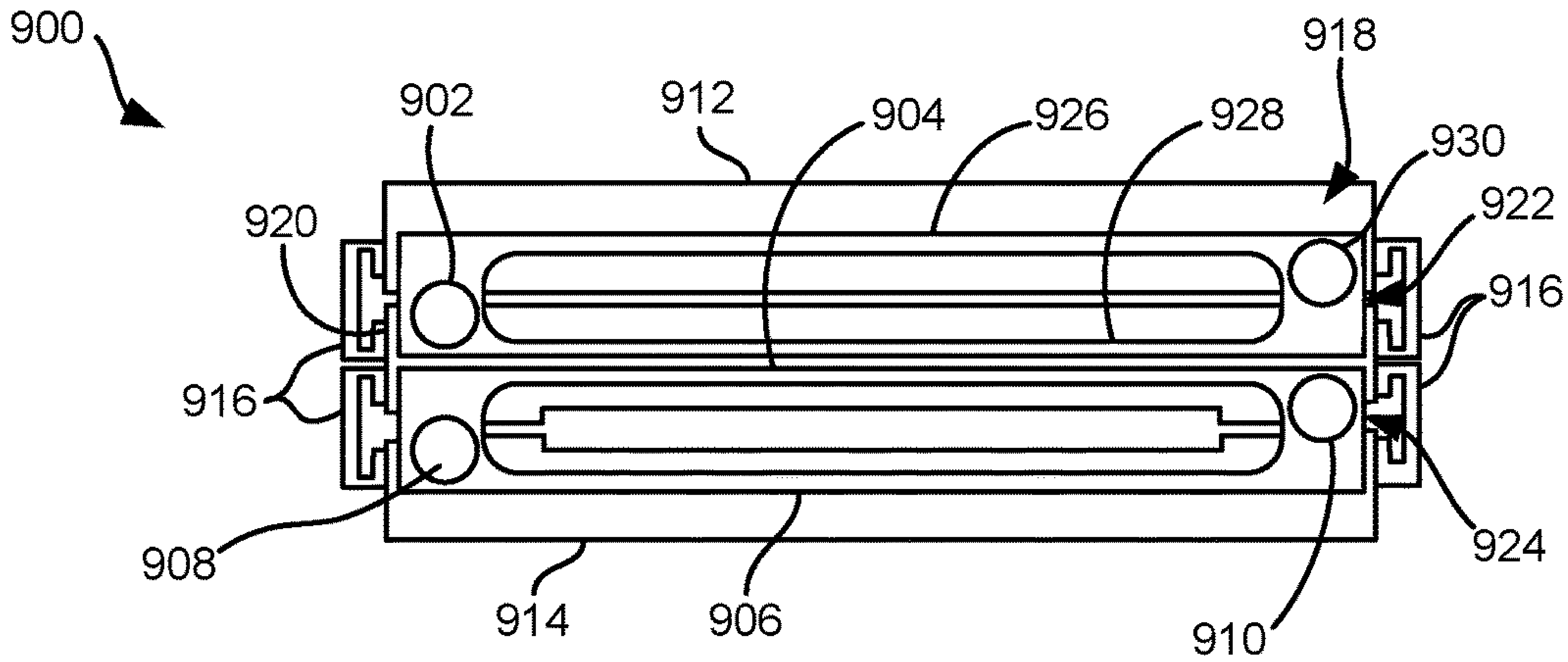


FIG. 9A

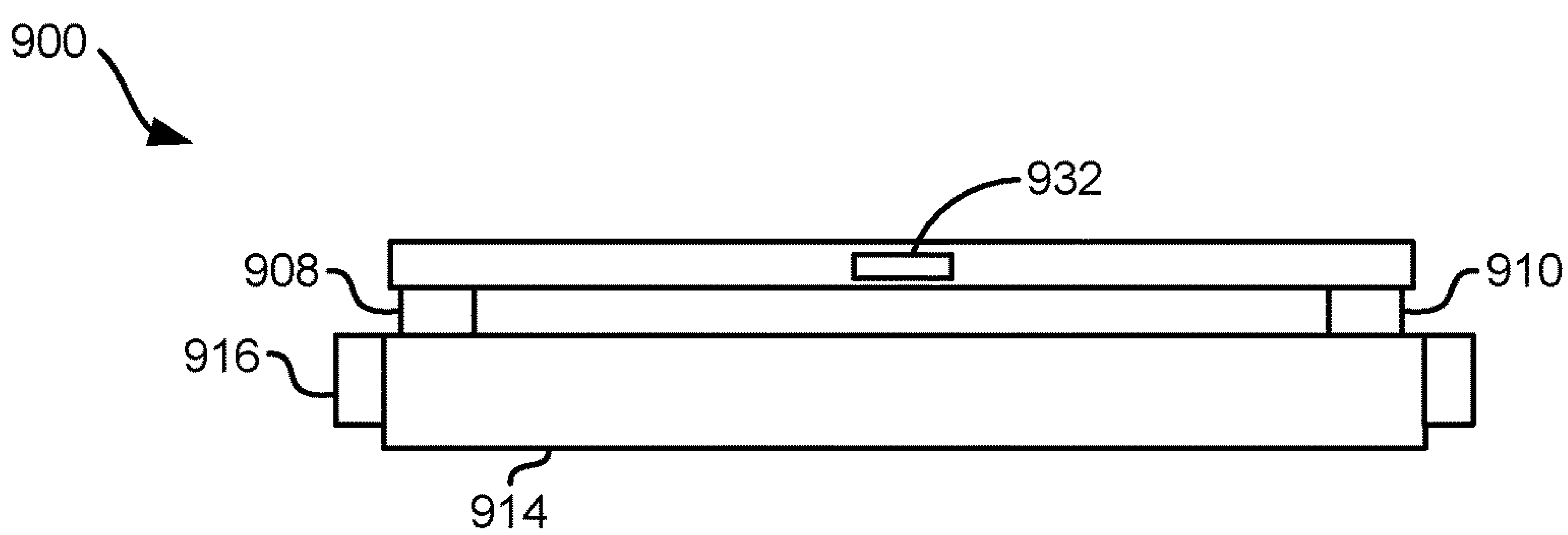


FIG. 9B

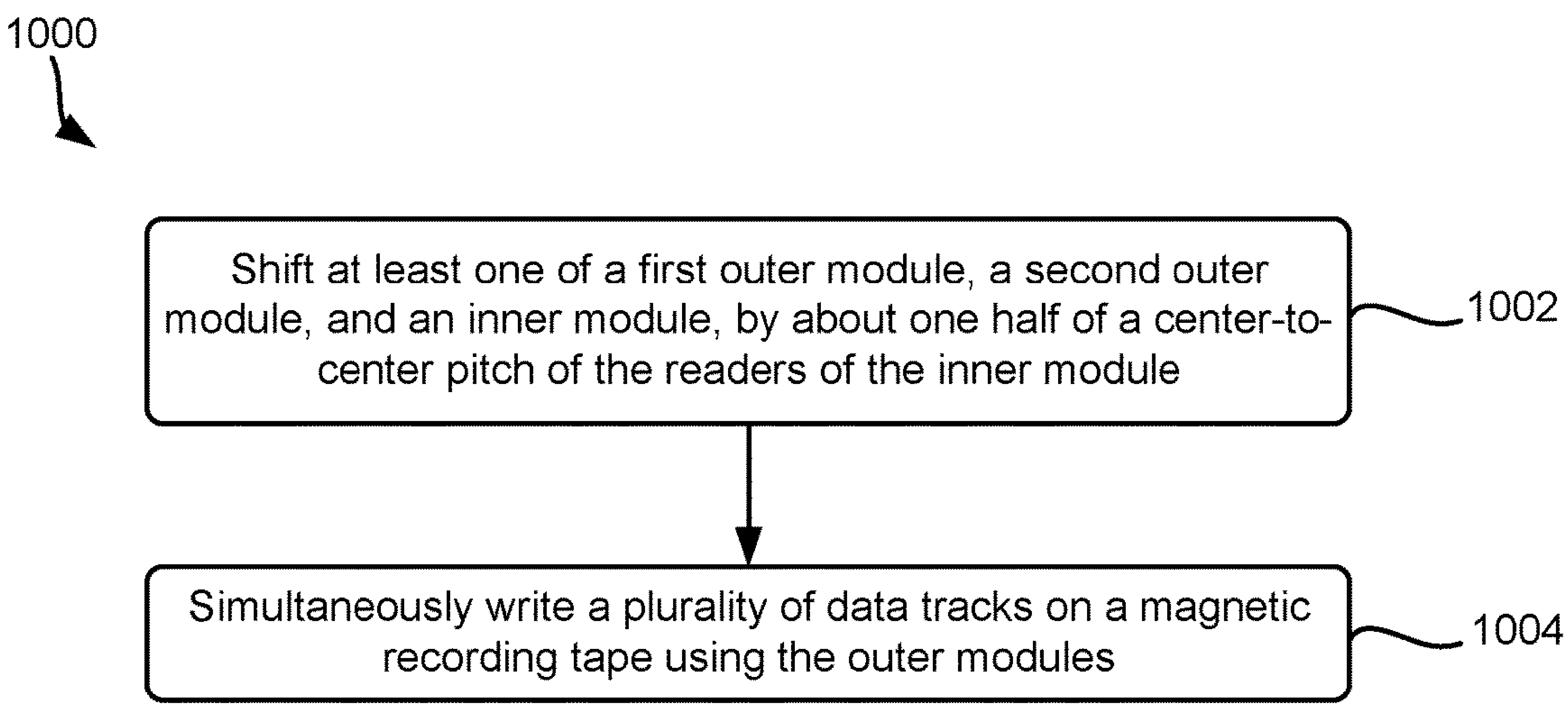

1000
Shift at least one of a first outer module, a second outer module, and an inner module, by about one half of a center-to-center pitch of the readers of the inner module
1002
Simultaneously write a plurality of data tracks on a magnetic recording tape using the outer modules
1004

FIG. 10

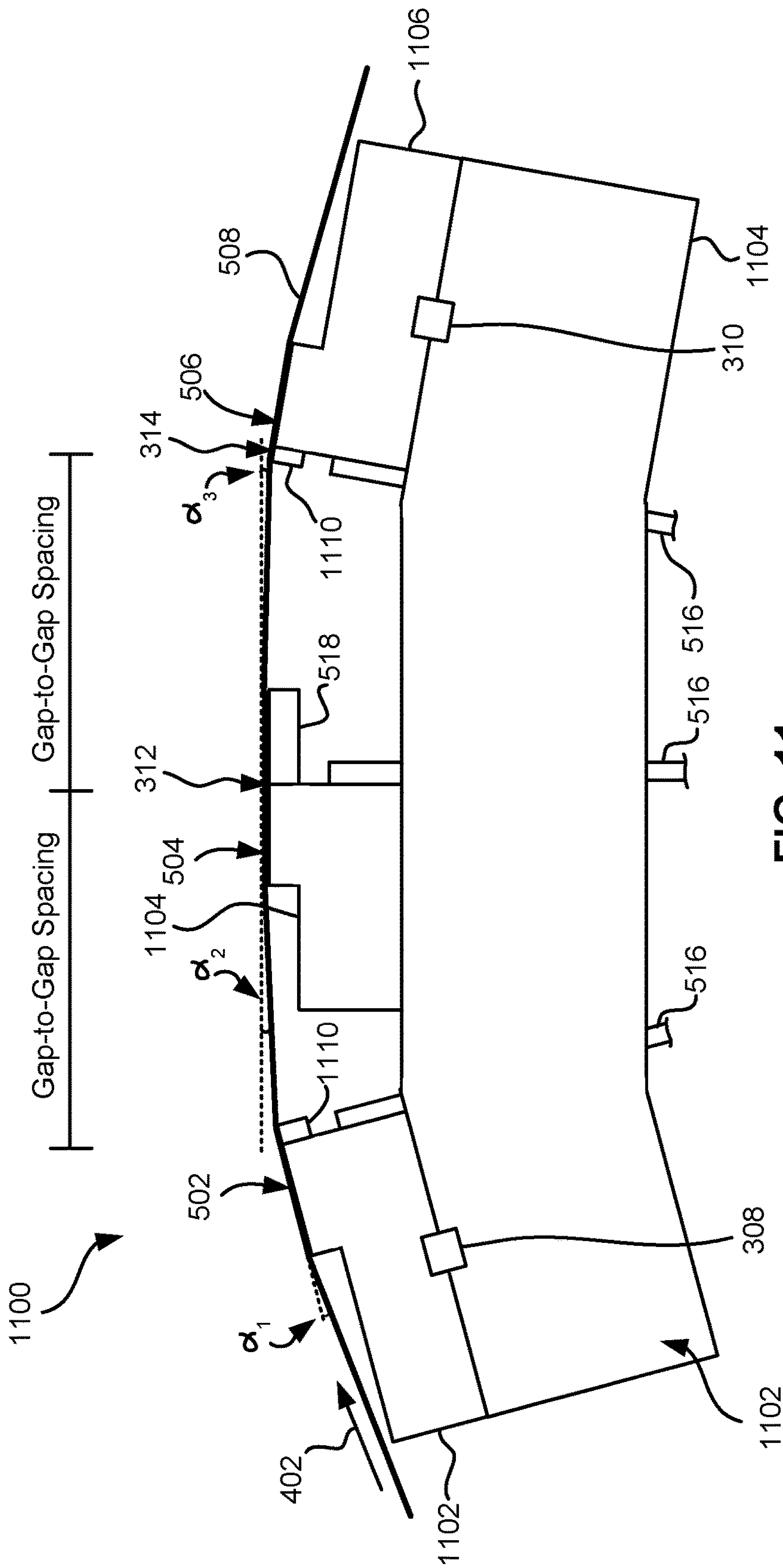

1100
1106
508
1104
310
506
314
α_3
1110
Gap-to-Gap Spacing
518
516
516
312
504
1104
α_2
Gap-to-Gap Spacing
1110
516
502
308
α_1
402
1102
1102

FIG. 11

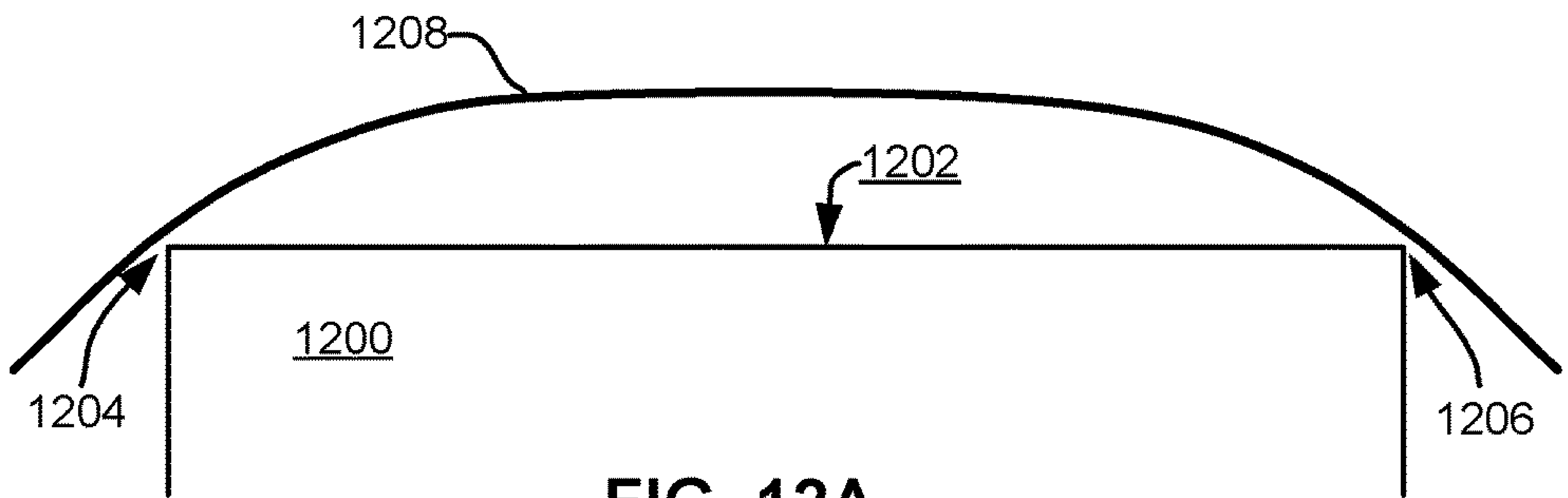


FIG. 12A

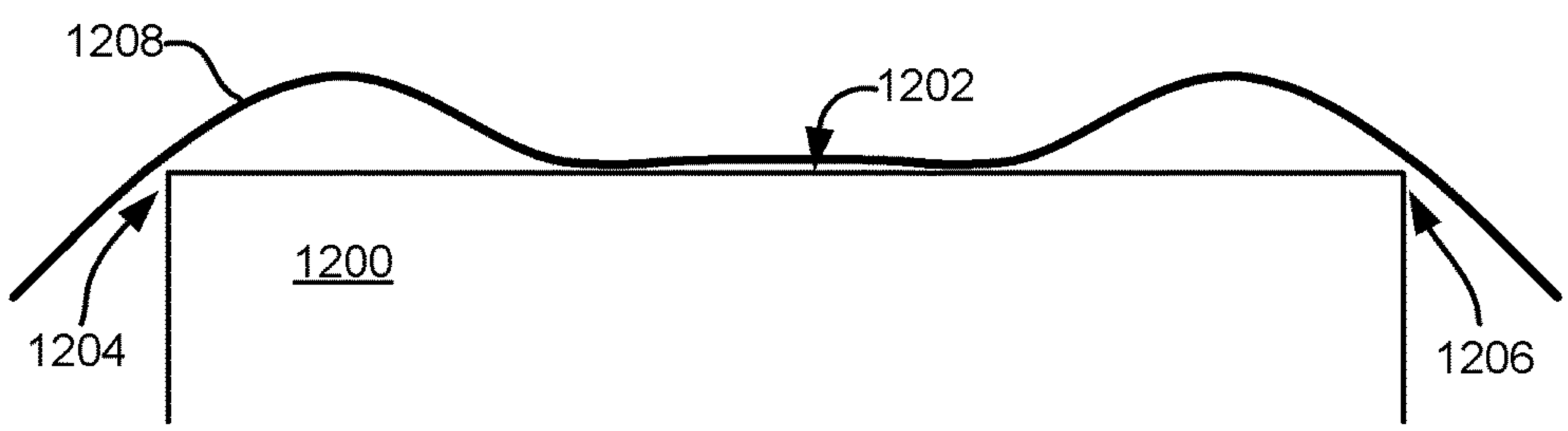


FIG. 12B

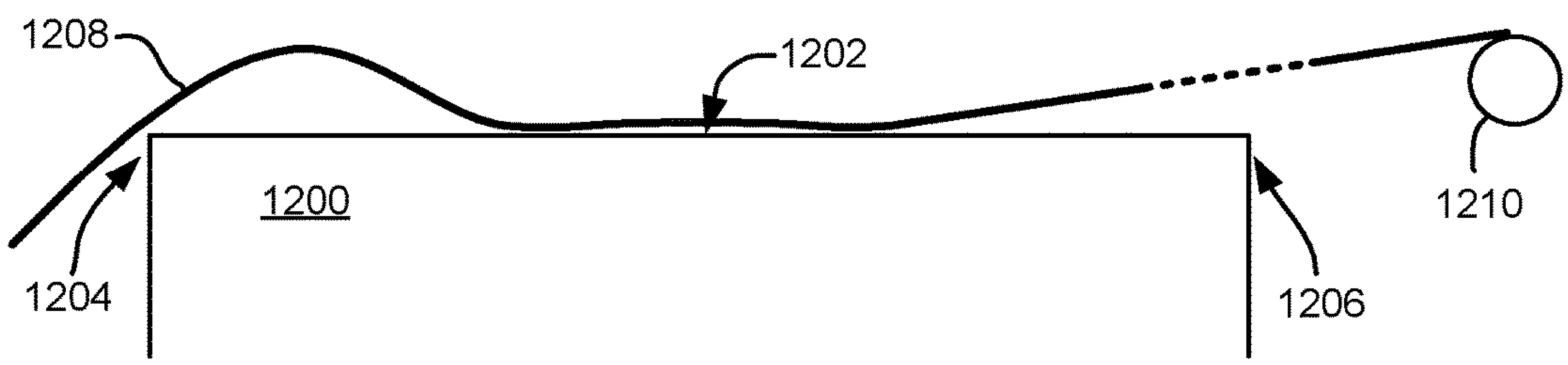


FIG. 12C

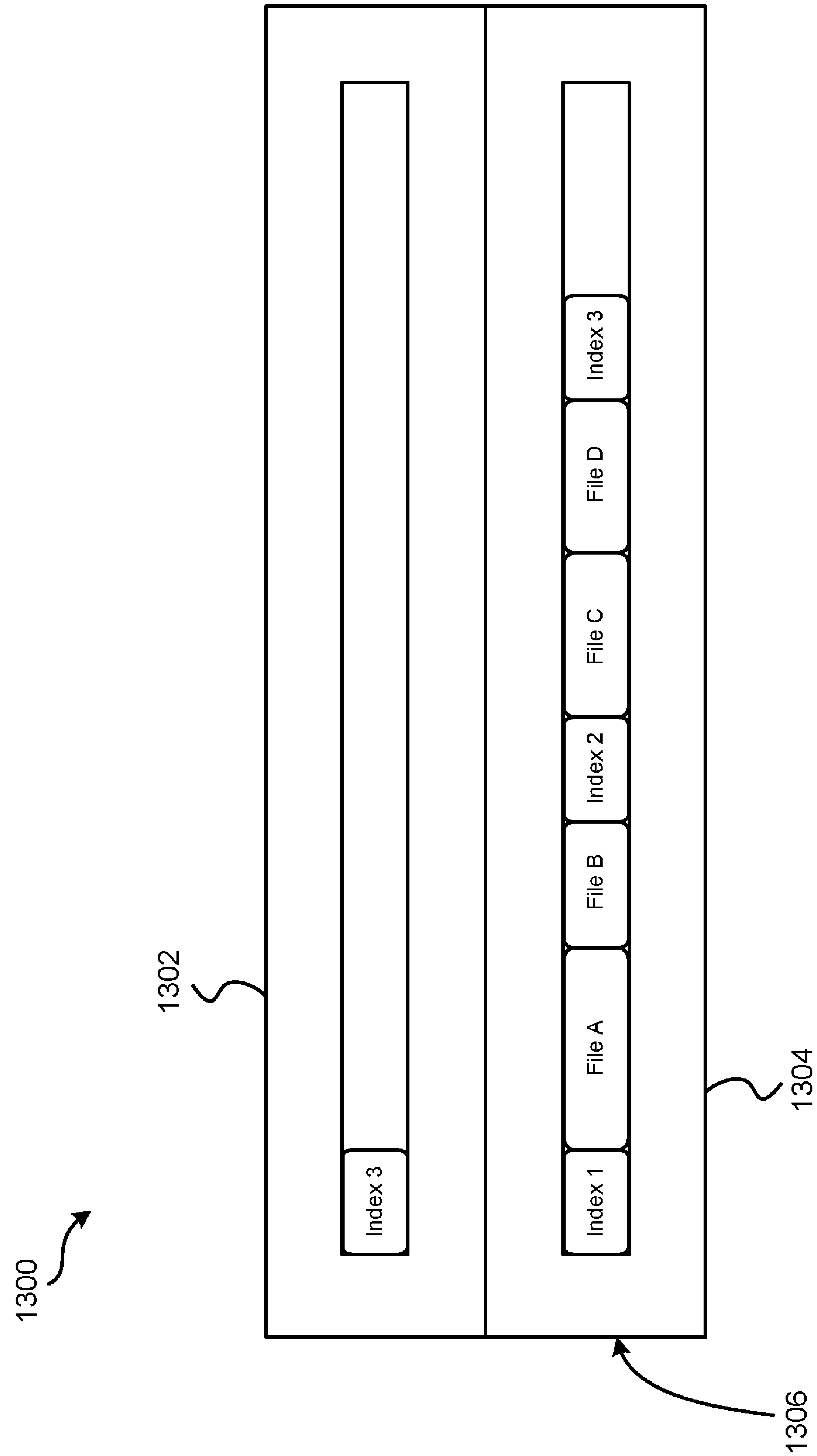

1300
1302
1304
1306
Index 3
Index 1
File A
File B
Index 2
File C
File D
Index 3

FIG. 13

UTILIZATION OF MULTIPLE WRITER MODULES FOR SIMULTANEOUSLY WRITING TWO TIMES THE NUMBER OF DATA TRACKS IN A COMPACT FORM FACTOR

BACKGROUND

The present invention relates to data storage systems, and more particularly, this invention relates to the selective shifting of modules of a magnetic recording head to enable simultaneous writing by writers of different write modules to different data tracks.

In magnetic storage systems, magnetic transducers read data from and write data onto magnetic recording media. Data is written on the magnetic recording media by moving a magnetic recording transducer to a position over the media where the data is to be stored. The magnetic recording transducer then generates a magnetic field, which encodes the data into the magnetic media. Data is read from the media by similarly positioning the magnetic read transducer and then sensing the magnetic field of the magnetic media. Read and write operations may be independently synchronized with the movement of the media to ensure that the data can be read from and written to the desired location on the media.

An important and continuing goal in the data storage industry is that of increasing the density of data stored on a medium. For tape storage systems, that goal has led to increasing the track and linear bit density on recording tape, and decreasing the thickness of the magnetic tape medium. However, the development of small footprint, higher performance tape drive systems has created various problems in the design of a tape head assembly for use in such systems.

In a tape drive system, the drive moves the magnetic tape over the surface of the tape head at high speed. Usually the tape head is designed to minimize the spacing between the head and the tape. The spacing between the magnetic head and the magnetic tape is crucial and so goals in these systems are to have the recording gaps of the transducers, which are the source of the magnetic recording flux in near contact with the tape to effect writing sharp transitions, and to have the read elements in near contact with the tape to provide effective coupling of the magnetic field from the tape to the read elements.

SUMMARY

An apparatus according to one embodiment includes a first outer module having an array of writers, a second outer module having an array of writers, an inner module positioned between the outer modules, and a first actuator for shifting the first outer module. The shifting is relative to the inner module, in a cross-track direction by about one half of a center-to-center pitch of the writers of the first outer module. The inner module has an array of readers.

An apparatus according to another embodiment includes a first outer module having an array of writers, a second outer module having an array of writers, an inner module positioned between the outer modules, and an actuator for shifting the inner module. The shifting is relative to the outer modules, for selectively aligning the readers with the writers of the outer modules depending on tape travel direction. The writers of the second outer module being offset from the writers of the first outer module in a cross-track direction by about one half of a center-to-center pitch of the writers of the second outer module, positions of the first and second outer modules being fixed relative to one another. The inner module has an array of readers.

A tape drive-implemented method may be implemented in a tape drive having at least a first outer module having an array of writers, a second outer module having an array of writers, and an inner module positioned between the outer modules, the inner module having an array of readers, according to one embodiment. The method includes shifting at least one of the modules by about one half of a center-to-center pitch of the readers of the inner module, and simultaneously writing a plurality of data tracks on a magnetic recording tape using the outer modules. The data tracks written by a trailing one of the outer modules are offset in a cross-track direction from the data tracks written by a leading one of the outer modules.

Any of these embodiments may be implemented in a magnetic data storage system such as a tape drive system, which may include a magnetic head, a drive mechanism for passing a magnetic medium (e.g., recording tape) over the magnetic head, and a controller electrically coupled to the magnetic head.

Other aspects and embodiments of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a schematic diagram of a simplified tape drive system according to one embodiment.

FIG. **1**B is a schematic diagram of a tape cartridge according to one embodiment.

FIG. **2**A illustrates a side view of a flat-lapped, bi-directional, two-module magnetic tape head according to one embodiment.

FIG. **2**B is a tape bearing surface view taken from Line **2**B of FIG. **2**A.

FIG. **2**C is a detailed view taken from Circle **2**C of FIG. **2**B.

FIG. **2**D is a detailed view of a partial tape bearing surface of a pair of modules.

FIG. **3** is a partial tape bearing surface view of a magnetic head having a write-read-write configuration, where one of the outer modules is shifted via an actuator, in accordance with one embodiment.

FIG. **4** is a partial tape bearing surface view of the magnetic head of FIG. **3** where the other outer module is shifted via an actuator.

FIG. **5** is a side view of a magnetic tape head with three modules and actuators, in a tangent (angled) configuration.

FIG. **6**A is a partial tape bearing surface view of a magnetic head having a write-read-write configuration, where the inner module is shifted via an actuator, in accordance with one embodiment.

FIG. **6**B is a partial tape bearing surface view of the magnetic head of FIG. **6**A, where the inner module is shifted via the actuator.

FIG. **7** is a side view of a magnetic tape head with three modules and an actuator, in a tangent (angled) configuration.

FIG. **8** is a bottom view of modules and an actuator, in accordance with one embodiment.

FIGS. **9**A-**9**B are bottom and side views, respectively, of modules of a magnetic tape head according to one embodiment.

FIG. **10** is a flowchart of a method, in accordance with one embodiment.

FIG. **11** is a side view of a magnetic tape head with three modules in an overwrap configuration.

FIGS. **12**A-**12**C are schematics depicting the principles of tape tenting.

FIG. **13** is a representational diagram of files and indexes stored on a magnetic tape according to one embodiment.

DETAILED DESCRIPTION

The following description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations.

Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

It must also be noted that, as used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless otherwise specified.

The following description discloses several preferred embodiments of increasing simultaneous writing capacity in a magnetic storage system, as well as operation and/or component parts thereof.

In one general embodiment, an apparatus includes a first outer module having an array of writers, a second outer module having an array of writers, an inner module positioned between the outer modules, and a first actuator for shifting the first outer module. The shifting is relative to the inner module, in a cross-track direction by about one half of a center-to-center pitch of the writers of the first outer module. The inner module has an array of readers.

In another general embodiment, an apparatus includes a first outer module having an array of writers, a second outer module having an array of writers, an inner module positioned between the outer modules, and an actuator for shifting the inner module. The shifting is relative to the outer modules, for selectively aligning the readers with the writers of the outer modules depending on tape travel direction. The writers of the second outer module being offset from the writers of the first outer module in a cross-track direction by about one half of a center-to-center pitch of the writers of the second outer module, positions of the first and second outer modules being fixed relative to one another. The inner module has an array of readers.

In yet another general embodiment, a tape drive-implemented method may be implemented in a tape drive having at least a first outer module having an array of writers, a second outer module having an array of writers, and an inner module positioned between the outer modules, the inner module having an array of readers. The method includes shifting at least one of the modules by about one half of a center-to-center pitch of the readers of the inner module, and simultaneously writing a plurality of data tracks on a magnetic recording tape using the outer modules. The data tracks written by a trailing one of the outer modules are offset in a cross-track direction from the data tracks written by a leading one of the outer modules.

FIG. **1**A illustrates a simplified tape drive **100** of a tape-based data storage system, which may be employed in the context of the present invention. While one specific implementation of a tape drive is shown in FIG. **1**A, it should be noted that the embodiments described herein may be implemented in the context of any type of tape drive system.

As shown, a tape supply cartridge **120** and a take-up reel **121** are provided to support a tape **122**. One or more of the reels may form part of a removable cartridge and are not necessarily part of the system **100**. The tape drive, such as that illustrated in FIG. **1**A, may further include drive motor(s) to drive the tape supply cartridge **120** and the take-up reel **121** to move the tape **122** over a tape head **126** of any type. Such head may include an array of readers, writers, or both.

Guides **125** guide the tape **122** across the tape head **126**. Such tape head **126** is in turn coupled to a controller **128** via a cable **130**. The controller **128**, may be or include a processor and/or any logic for controlling any subsystem of the drive **100**. For example, the controller **128** typically controls head functions such as servo following, data writing, data reading, etc. The controller **128** may include at least one servo channel and at least one data channel, each of which include data flow processing logic configured to process and/or store information to be written to and/or read from the tape **122**. The controller **128** may operate under logic known in the art, as well as any logic disclosed herein, and thus may be considered as a processor for any of the descriptions of tape drives included herein, in various embodiments. The controller **128** may be coupled to a memory **136** of any known type, which may store instructions executable by the controller **128**. Moreover, the controller **128** may be configured and/or programmable to perform or control some or all of the methodology presented herein. Thus, the controller **128** may be considered to be configured to perform various operations by way of logic programmed into one or more chips, modules, and/or blocks; software, firmware, and/or other instructions being available to one or more processors; etc., and combinations thereof.

The cable **130** may include read/write circuits to transmit data to the head **126** to be recorded on the tape **122** and to receive data read by the head **126** from the tape **122**. An actuator **132** controls position of the head **126** relative to the tape **122**.

An interface **134** may also be provided for communication between the tape drive **100** and a host (internal or external) to send and receive the data and for controlling the operation of the tape drive **100** and communicating the status of the tape drive **100** to the host, all as will be understood by those of skill in the art.

FIG. **1**B illustrates an exemplary tape cartridge **150** according to one embodiment. Such tape cartridge **150** may be used with a system such as that shown in FIG. **1**A. As shown, the tape cartridge **150** includes a housing **152**, a tape **122** in the housing **152**, and a nonvolatile memory **156** coupled to the housing **152**. In some approaches, the nonvolatile memory **156** may be embedded inside the housing **152**, as shown in FIG. **1**B. In more approaches, the nonvolatile memory **156** may be attached to the inside or outside of the housing **152** without modification of the housing **152**. For example, the nonvolatile memory may be embedded in a self-adhesive label **154**. In one preferred embodiment, the nonvolatile memory **156** may be a Flash memory device, read-only memory (ROM) device, etc., embedded into or coupled to the inside or outside of the tape cartridge **150**. The nonvolatile memory is accessible by the tape drive and the tape operating software (the driver software), and/or another device.

By way of example, FIG. **2**A illustrates a side view of a flat-lapped, bi-directional, two-module magnetic tape head **200** which may be implemented in the context of the present invention. As shown, the head includes a pair of bases **202**, each equipped with a module **204**, and fixed at a small angle α with respect to each other. The bases may be "U-beams" that are adhesively coupled together. Each module **204** includes a substrate **204**A and a closure **204**B with a thin film portion, commonly referred to as a "gap" in which the readers and/or writers **206** are formed. In use, a tape **208** is moved over the modules **204** along a media (tape) bearing surface **209** in the manner shown for reading and writing data on the tape **208** using the readers and writers. The wrap angle θ of the tape **208** at edges going onto and exiting the flat media support surfaces **209** are usually between about 0.1 degree and about 3 degrees.

The substrates **204**A are typically constructed of a wear resistant material, such as a ceramic. The closures **204**B may be made of the same or similar ceramic as the substrates **204**A.

The readers and writers may be arranged in a piggyback or merged configuration. An illustrative piggybacked configuration comprises a (magnetically inductive) writer transducer on top of (or below) a (magnetically shielded) reader transducer (e.g., a magnetoresistive reader, etc.), wherein the poles of the writer and the shields of the reader are generally separated. An illustrative merged configuration comprises one reader shield in the same physical layer as one writer pole (hence, "merged"). The readers and writers may also be arranged in an interleaved configuration. Alternatively, each array of channels may be readers or writers only. Any of these arrays may contain one or more servo track readers for reading servo data on the medium.

FIG. **2**B illustrates the tape bearing surface **209** of one of the modules **204** taken from Line **2**B of FIG. **2**A. A representative tape **208** is shown in dashed lines. The module **204** is preferably long enough to be able to support the tape as the head steps between data bands.

In this example, the tape **208** includes 4 to 32 data bands, e.g., with 16 data bands and 17 servo tracks **210**, as shown in FIG. **2**B on a one-half inch wide tape **208**. The data bands are defined between servo tracks **210**. Each data band may include a number of data tracks, for example 1024 data tracks (not shown). During read/write operations, the readers and/or writers **206** are positioned to specific track positions within one of the data bands. Outer readers, sometimes called servo readers, read the servo tracks **210**. The servo signals are in turn used to keep the readers and/or writers **206** aligned with a particular set of tracks during the read/write operations.

FIG. **2**C depicts a plurality of readers and/or writers **206** formed in a gap **218** on the module **204** in Circle **2**C of FIG. **2**B. As shown, the array of readers and writers **206** includes, for example, 16 writers **214**, 16 readers **216** and two servo readers **212**, though the number of elements may vary. Illustrative embodiments include 8, 16, 32, 40, and 64 active readers and/or writers **206** per array, and alternatively interleaved designs having odd numbers of reader or writers such as 17, 25, 33, etc. An illustrative embodiment includes 32 readers per array and/or 32 writers per array, where the actual number of transducer elements could be greater, e.g., 33, 34, etc. This allows the tape to travel more slowly, thereby reducing speed-induced tracking and mechanical difficulties and/or execute fewer "wraps" to fill or read the tape. While the readers and writers may be arranged in a piggyback configuration as shown in FIG. **2**C, the readers **216** and writers **214** may also be arranged in an interleaved configuration. Alternatively, each array of readers and/or writers **206** may be readers or writers only, and the arrays may contain one or more servo readers **212**. As noted by considering FIGS. **2**A and **2**B-**2**C together, each module **204** may include a complementary set of readers and/or writers **206** for such things as bi-directional reading and writing, read-while-write capability, backward compatibility, etc.

FIG. **2**D shows a partial tape bearing surface view of complementary modules of a magnetic tape head **200** according to one embodiment. In this embodiment, each module has a plurality of read/write (R/W) pairs in a piggyback configuration formed on a common substrate **204**A and an optional electrically insulative layer **236**. The writers, exemplified by the write transducer **214** and the readers, exemplified by the read transducer **216**, are aligned parallel to an intended direction of travel of a tape medium thereacross to form an R/W pair, exemplified by the R/W pair **222**. Note that the intended direction of tape travel is sometimes referred to herein as the direction of tape travel, and such terms may be used interchangeably. Such direction of tape travel may be inferred from the design of the system, e.g., by examining the guides; observing the actual direction of tape travel relative to the reference point; etc. Moreover, in a system operable for bi-direction reading and/or writing, the direction of tape travel in both directions is typically parallel and thus both directions may be considered equivalent to each other.

Several R/W pairs **222** may be present, such as 8, 16, 32 pairs, etc. The R/W pairs **222** as shown are linearly aligned in a direction generally perpendicular to a direction of tape travel thereacross. However, the pairs may also be aligned diagonally, etc. Servo readers **212** are positioned on the outside of the array of R/W pairs, the function of which is well known.

Generally, the magnetic tape medium moves in either a forward or reverse direction as indicated by arrow **220**. The magnetic tape medium and head assembly **200** operate in a transducing relationship in the manner well-known in the art. The piggybacked magnetoresistive (MR) head assembly **200** includes two thin-film modules **224** and **226** of generally identical construction.

Modules **224** and **226** are joined together with a space present between closures **204**B thereof (partially shown) to form a single physical unit to provide read-while-write capability by activating the writer of the leading module and reader of the trailing module aligned with the writer of the leading module parallel to the direction of tape travel relative thereto. When a module **224**, **226** of a piggyback head **200** is constructed, layers are formed in the gap **218** created above an electrically conductive substrate **204**A (partially shown), e.g., of AlTiC, in generally the following order for the R/W pairs **222**: an insulating layer **236**, a first shield **232** typically of an iron alloy such as NiFe (—), cobalt zirconium tantalum (CZT) or Al—Fe—Si (Sendust), a sensor **234** for sensing a data track on a magnetic medium, a second shield **238** typically of a nickel-iron alloy (e.g., ~80/20 at % NiFe, also known as permalloy), first and second writer pole tips **228**, **230**, and a coil (not shown). The sensor may be of any known type, including those based on MR, GMR, AMR, tunneling magnetoresistance (TMR), etc.

The first and second writer poles **228**, **230** may be fabricated from high magnetic moment materials such as ~45/55 NiFe. Note that these materials are provided by way of example only, and other materials may be used. Additional layers such as insulation between the shields and/or pole tips and an insulation layer surrounding the sensor may be present. Illustrative materials for the insulation include alumina and other oxides, insulative polymers, etc.

The configuration of the tape head **126** according to one embodiment includes multiple modules, preferably three or more. In a write-read-write (W-R-W) head, outer modules for writing flank one or more inner modules for reading.

Each of the writers of a first write module in a conventional W-R-W head are often aligned along the same data tracks as a corresponding writer of a second write module of the conventional W-R-W head. Accordingly, each of the writers of the conventional first write module would write to the same respective data tracks as the correspondingly paired writer of a second write module, if the writers of both modules were activated simultaneously. Embodiments described herein include implementing actuators in magnetic tape drives for the selective shifting of one or more modules to enable simultaneous writing by writers of different write modules to different data tracks.

FIGS. **3-5** depict a system **300** in accordance with one embodiment. As an option, the present system **300** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such system **300** and others presented herein may be used in various applications and/or in permutations which may or may not be specifically described in the illustrative embodiments listed herein. Further, the system **300** presented herein may be used in any desired environment.

Referring now to FIG. **3**, system **300** includes an apparatus **318**. The apparatus **318** may be the system **300** or a portion thereof.

Apparatus **318** includes a first outer module **302** having an array of writers **314**, and a second outer module **306** having an array of writers **314**.

Apparatus **318** also includes an inner module **304** positioned between the outer modules **302**, **306**. The inner module **304** may have an array of readers **312**.

Variations of a multi-module head include arrangements in which one or more of the modules may have read/write pairs of transducers. Moreover, more than three modules may be present. In further approaches, two outer modules may flank two or more inner modules, e.g., in a W-R-R-W, a R-W-W-R arrangement, etc. For simplicity, a W-R-W head is used primarily herein to exemplify a few of the many possible embodiments of the present invention. One skilled in the art apprised with the teachings herein will appreciate how permutations of the present description may apply to various configurations other than a W-R-W configuration.

A magnetic recording medium, e.g., a magnetic recording tape, hereafter referred to as "tape," may be passed over each of the modules **302**, **304**, **306** in a first direction **316**. It should be noted that the tape is not illustrated in FIGS. **3-4** for simplicity; however, the tape may be seen in FIG. **5**, which illustrates a partial tape bearing surface view of system **300**.

Apparatus **318** includes a first actuator **308** for shifting the first outer module **302**. According to various embodiments, the first actuator **308** may shift the first outer module **302**, relative to the inner module **304**, in a cross-track direction, e.g., a direction about orthogonal to the first direction **316**. The shift may be about one half of a center-to-center pitch **322** of the writers **314** of the first outer module **302** when writing in a direction in which the second outer module **306** is the leading module. To clarify, the leading module may be the first module the tape encounters when traveling in a given direction, e.g., the second outer module **306** is the leading module in FIG. **3** (with respect to tape traveling in the first direction **316**).

Although the first outer module **302** is shifted about one half of a center-to-center pitch **322** of the writers **314** of the first outer module **302** in the present embodiment, according to other embodiments, the first actuator **308** may shift the first outer module **302** to some other position whereby the writers **314** of the first outer module **302** write data tracks **320** in a different location than the data tracks **320** that the writers **314** of the second outer module **304** are positioned to write simultaneously therewith.

Actuators described in this and other embodiments described herein may include any type of conventional actuator. According to various embodiments, the first actuator **308** may include, e.g., a worm screw, a piezo stack, a microscopic voice coil magnet assembly, a micro eletro mechanical structure (MEMS) device, etc. The first actuator **308** may additionally and/or alternatively include a biasing mechanism, e.g., a spring, which may be used to retract the outer module(s) **302**, **306** from a most previous shifting motion to a nominal position. Actuator springs will be described in greater detail elsewhere herein, e.g., see FIGS. **8-9**B.

Shifting the first outer module **302**, relative to the inner module **304**, in a cross-track direction may allow the writers of the first outer module **302** and the second outer module **306** to simultaneously write separate data tracks, at twice the rate achievable when only one of the modules is used. In other words, shifting the first outer module **302** in the system **300** of FIG. **3** may allow the 16 total writers of the outer modules **302**, **306** to write 16 separate data tracks on a magnetic recording tape that is passed over the writers **314**. These 16 separate data tracks include 8 more written data tracks than would be written if the first outer module **302** were not shifted by the actuator **308**. This is because, as previously described, in the un-shifted position, the writers **314** of the first outer module **302** align with writers **314** of the second outer module **306** along the first direction **316** and the writers **314** thereby are only able to write 8 data tracks (in the present example). Likewise, where each module has an array of 32 writers, the shift may correspond to a simultaneous writing potential of 64 data channels as opposed to 32 data channels.

Referring now to FIG. **4**, the tape may be passed over each of the modules **302**, **304**, **306** in a second direction **402**. The second direction **402** may be substantially opposite the first direction **316** of FIG. **3**.

The second actuator **310** may shift the second outer module **306**. According to various embodiments, the second actuator **310** may shift the second outer module **306** relative to the inner module **304**. The shift may be about one half of a center-to-center pitch **404** of the writers **314** of the second outer module **306** when writing in the direction **402** in which the first outer module **302** is the leading module, or some other distance.

Shifting the second outer module **306**, relative to the inner module **304**, in the cross-track direction may allow each of the writers **314** of the first outer module **302** and the second outer module **306** to simultaneously write separate data tracks in the second direction **402** of tape travel.

It should be noted that in FIGS. **3** and **4**, the dashed lines "**320**" represent data tracks **320** that may be written to a tape that passes over the modules **302**, **304**, **306**. The data tracks **320** are written by the writers **314** of both outer modules **302**, **306**. As shown in FIGS. **3-4**, preferably the tracks written by the writers **314** of the leading module, as determined by tape travel direction, are aligned with the readers **312** of the inner module **304**, thereby allowing read-while-write verification of the data tracks written by the leading module. While the tracks written by the trailing module are not immediately read-verified in the embodiment shown in FIGS. **3-4**, the data may be verified later, or simply not verified.

The apparatus **318** may include a drive mechanism to pass a magnetic recording tape over each of the modules **302**, **304**, **306**. Apparatus **318** may also include a controller electrically coupled to the readers **312** and writers **314**. In the present illustrative embodiment, the controller may be configured to read-verify tracks written by writers **314** of the outer modules **302**, **306** using signals from the readers **312** of the inner module **304**. An illustrative drive and controller are described elsewhere herein, e.g., see FIG. **1**A.

As is illustrated in FIG. **5**, system **300** may include three cables **516** that enable both conventional bi-directional read-while-write writing of 8 data tracks, and simultaneous writing of 16 data tracks. Accordingly, the first actuator **308** desirably enables an increase in the number of available write channels without the need for extra head cables. This is especially desirable because adding extra cables may undesirably crowd the tight and compact spatial constraints in a drive; and moreover, the stiffness of the additional cables would be expected to adversely affect the performance of the track following actuator. In comparison, an implemented first actuator **308**, and even an additionally implemented second actuator (as will be described elsewhere herein), may preferably be very small in size.

It should be noted that although sixteen data tracks **320** corresponding to sixteen writers, are illustrated in FIG. **3**, system **300** may include any number of data channels according to other embodiments. For example, according to one approach, the system **300** may include 32 writers. According to another approach, the system **300** may include 32 writers. According to yet another approach, the system **300** may include 64 writers. Moreover, the number of readers of the inner module **304** relative to the number of writers of the outer modules **302**, **306** may vary, depending on the embodiment.

According to various embodiments, apparatus **318** may additionally and/or alternatively include a skew compensation actuator (not shown). As tape is passed over the modules **302**, **304**, **306**, the skew compensation actuator may rotate the modules **302**, **304**, **306** to compensate for tape skew.

According to other embodiments, the modules **302**, **304**, **306** may be coupled to a conventional two-stage actuator, e.g., a coarse and fine track following two-stage actuator, with the first and second actuators **308**, **310** providing the aforementioned further movement of the respective module. In various embodiments, a skew following function may also be enabled if desirable.

FIG. **5** illustrates a partial tape bearing surface view of system **300** in accordance with one embodiment. The modules **302**, **304**, **306** each have a tape bearing surface **502**, **504**, **506** respectively, which may be flat, contoured, etc. Note that while the term "tape bearing surface" appears to imply that the tape **508** is in physical contact with the tape bearing surface, this is not necessarily the case. Rather, only a portion of the tape **508** may be in contact with the tape bearing surface, constantly or intermittently, with other portions of the tape riding (or "flying") above the tape bearing surface on a layer of air, sometimes referred to as an "air bearing". The first outer module **302** will be referred to as the "leading module **302**" in the descriptions of FIG. **5** as it is the first module encountered by the tape **508** in a three module design for tape moving in the second direction **402**. The second outer module **306** will be referred to as the "trailing module **306**". The trailing module **306** follows the inner module **304** and is the last module seen by the tape **508** in a three module design. Note that the outer modules **302**, **306** will alternate as leading modules, depending on the direction of travel of the tape **508**.

In one embodiment, the tape bearing surfaces **502**, **504**, **506** of the modules **302**, **304**, **306** lie along planes slightly angled with respect to each other, and the tape bearing surface **504** of the inner module **304** is above the tape bearing surfaces **502**, **506** of the leading and trailing modules **302**, **306**. As described below, this has the effect of creating the desired wrap angle $\alpha 2$ of the tape **508** relative to the tape bearing surface **504** of the inner module **304**.

Depending on tape tension and stiffness, it may be desirable to angle the tape bearing surfaces of the outer modules **302**, **306** relative to the tape bearing surface of the inner module **304**. In FIG. **5**, the modules are in a tangent or nearly tangent (angled) configuration. Particularly, the tape bearing surfaces of the outer modules are about parallel to the tape at the desired wrap angle $\alpha 2$ of the second outer module. In other words, the planes of the tape bearing surfaces **502**, **506** of the outer modules are oriented at about the desired wrap angle $\alpha 2$ of the tape **508** relative to the inner module **304**.

The inner wrap angle $\alpha 2$ on the side of the inner module **304** receiving the tape (leading edge) and the inner wrap angle $\alpha 3$ on the trailing edge of the inner module **304** may vary depending on the embodiment. In preferred approaches, the wrap angles $\alpha 2$, $\alpha 3$ are adjusted such that the tape **508** is passed over the tape bearing surfaces **502**, **506** of the leading and trailing modules **302**, **306** such that each of the writers **314** of such modules **302**, **306** may simultaneously write separate data tracks.

As described elsewhere herein (see FIGS. **3-4**) to enable the writers **314** of the leading and trailing modules **302**, **306** to simultaneously write separate data tracks, according to various embodiments, a first actuator **308** may shift the leading module **302** relative to the inner module **304**, in a cross-track direction by about one half of a center-to-center pitch of the writers **314** of the leading module **302**. Likewise, the second actuator **310** may shift the trailing module **306** relative to the inner module **304**, in a cross-track direction by about one half of a center-to-center pitch of the writers **314** of the trailing module **306**.

The actuators **308**, **310** may reside on and/or contact a support **520** of any type that would become apparent to one skilled in the art upon reading the present disclosure. In one approach, the support may be a conventional head carriage, modified to accommodate the actuators **308**, **310**.

Writing and reading functions may be performed by different modules **302**, **304**, **306** at any given time. In one embodiment, the inner module **304** includes a plurality of data readers **312** and optional servo readers (not shown) but no writers. The leading and trailing modules **302**, **306** include a plurality of writers **314** and no data readers, with the exception that the leading and trailing modules **302**, **306** may include optional servo readers. The servo readers may be used to position the head during reading and/or writing operations. The servo reader(s) on each module **302**, **304**, **306** are typically located toward the ends of the arrays of readers or writers. Note that other embodiments described herein may or may not include servo readers, e.g., of conventional type, adjacent one or more of the arrays.

In some embodiments, the inner module **304** has a closure **518**, while the leading and trailing modules **302**, **306** do not have a closure. Where there is no closure, preferably a hard coating is added to the outer modules **302**, **306**. One preferred coating is diamond-like carbon (DLC). In other approaches, the outer modules **302**, **306** each have a closure.

It should be noted that apparatus **318** may according to other embodiments be used where modules are configured in an overwrap configuration. Such embodiments will be described elsewhere herein, e.g., see FIG. **11**.

In an alternate embodiment, an actuator may additionally and/or alternatively be configured to shift the inner module of a multi-module head, e.g., see FIGS. **6A-7**.

FIGS. **6A-7** depict a system **600** in accordance with one embodiment. As an option, the present system **600** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such system **600** and others presented herein may be used in various applications and/or in permutations which may or may not be specifically described in the illustrative embodiments listed herein. Further, the system **600** presented herein may be used in any desired environment.

It should be noted that various components of system **600** are similar to one or more components of system **300** of FIGS. **3-5**. Accordingly, one or more components of system **600** may share a common component numbering with one or more components of system **300**, and/or other systems described elsewhere herein.

Referring now to FIG. **6**A, system **600** includes an apparatus **608**. The apparatus **608** may be a portion of the system **600**. Apparatus **608** includes a first outer module **602** having an array of writers **314**. Apparatus **608** may also include a second outer module **606** having an array of writers **314**.

According to one embodiment, as illustrated in FIGS. **6**A-**6**B, the writers **314** of the second outer module **606** may be offset from the writers **314** of the first outer module **602** in a cross-track direction by about one half of a center-to-center pitch **616** of the writers **314** of the second outer module **606**. According to various embodiments, the positions of the first and second outer modules **602**, **606** may be fixed relative to one another.

Apparatus **608** may also include an inner module **604** positioned between the outer modules **602**, **606**. The inner module **604** may have an array of readers **312**.

Apparatus **608** may include an actuator **614** for shifting the inner module **604**, relative to the outer modules **602**, **606**. The actuator **614** for shifting the inner module **604** may selectively align the readers **312** with the writers **314** the leading outer module, depending on tape travel direction. In response to selectively aligning the readers **312** with the writers **314** of the leading outer module, during writing, the readers **312** of the inner module **304** may read-verify the data tracks written by the leading outer module.

Read verification in each tape travel direction will now be further detailed using a descriptive comparison of FIGS. **6**A-**6**B. Referring first to FIG. **6**A, the first outer module **602** is the leading write module and the second outer module **606** is the trailing write module in the first tape travel direction **610**, as shown in FIG. **6**A. In response to an instruction to move the tape in the first tape travel direction **610**, actuator **614** preferably shifts the inner module **604** to a position that selectively aligns the readers **312** of the inner module **604** with the writers **314** of the first outer module **602**. During tape travel in the first direction **610**, this selective alignment allows the writers **314** of the first outer module **602** to write data tracks, and then the readers **312** of the inner module **604** to read-verify those data tracks as the written data tracks pass over the readers **312**.

In contrast, referring now to FIG. **6**B, the second outer module **606** is the leading write module as the tape moves in the second tape travel direction **612**. In response to an instruction to move the tape in the second tape travel direction **612**, actuator **614** preferably shifts the inner module **604** to a position that selectively aligns the readers **312** of the inner module **604** with the writers **314** of the second outer module **606**. During tape travel in the second direction **612**, this selective alignment allows the writers **314** of the second outer module **606** to write data tracks, and then the readers **312** of the inner module **604** to read-verify those data tracks as the written data tracks pass over the readers **312**.

According to various embodiments, the data tracks written by the trailing one of the outer modules **602**, **606** may not be read-verified during a particular direction of tape travel. In such embodiments, the data tracks written by the trailing one of the outer modules **602**, **606** may however be read-verified in a second pass of the magnetic tape over the modules **602**, **604**, **606**. For example, referring again to FIG. **6**A, the data tracks written by the trailing outer module **606** may not be read-verified as the tape travels in the first direction **610**, e.g., during a first pass of the magnetic tape over the modules **602**, **604**, **606**. The data tracks written by the trailing outer module **606** during a first passing of the tape over the modules **602**, **604**, **606** may however be read-verified by the readers **312** of the inner module **604** during a second pass of the magnetic tape over the modules **602**, **604**, **606**, e.g., at the request of a user or host, when the drive has no read or write requests pending (e.g., idle time), etc.

Referring now to FIG. **7**, a side view of the modules **602**, **604**, **606** of system **600** is illustrated in accordance with one embodiment. In FIG. **7**, the modules are in a tangent or nearly tangent (angled) configuration.

A tape **508** is illustrated traveling in a first tape travel direction **610** in FIG. **7**. Consequently, the first outer module **602** is the leading write module. Actuator **614** may shift the inner module **604** to a position that selectively aligns the readers **312** of the inner module **604** with the writers **314** of the first outer module **602**, thereby enabling read-verification of data tracks written by writers **314** of the first outer module **602**.

The actuator **614** may reside on and/or contact a support **702** of any type.

FIG. **8-9**B depict systems **800**, **900** in accordance with various embodiments whereby illustrative actuators shift one or more modules of a three module head by exerting a force on one or more other modules. As an option, the present systems **800**, **900** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such systems **800**, **900** and others presented herein may be used in various applications and/or in permutations which may or may not be specifically described in the illustrative embodiments listed herein. Further, the systems **800**, **900** presented herein may be used in any desired environment.

Referring now to FIG. **8**, system **800** includes an actuator **824**. Actuator **824** may be coupled to a plurality of modules, e.g., see outer modules **802**, **822** and an inner module **804** of system **800**.

Note that FIG. **8** illustrates a bottom view of the modules **802**, **804**, **822** and actuator **824**, e.g., readers and writers of the modules **802**, **804**, **822** may reside on an opposite side of the modules **802**, **804**, **822** not visible in FIG. **8**.

Actuator **824** includes two preferably semi-rigid beams **810**, **820**. Each of the beams **810**, **820** may be coupled to two adjacent modules **802** and **804**, **804** and **822**, respectively, at or near opposite and alternate ends of the modules **802**, **804**, **822**. The coupling between the beams **810**, **820** and the modules **802**, **804**, **822** may be established using any conventional coupling type. According to various embodiments, the coupling may be established via, e.g., an adhesive, pins, solder, etc.

Actuator **824** may selectively cause a movement of each outer module **802**, **822** relative to the inner module **804** in an allowed direction of movement by exerting a force on the modules to which it is attached. For example, the outer module **802** may be shifted in a first direction **808** in response to a force being exerted on both the outer module **802** and the inner module **804** by beam **810**. According to another example, the outer module **822** may be shifted in the first direction **808** in response to a force being exerted on both the outer module **822** and the inner module **804** by beam **820**.

To hold the modules **802**, **804**, **822** in a desired position while allowing this motion, the modules **802**, **804**, **822** may be connected to one another by one or more springs **812** or other component(s) that allows flexing in the direction of motion. Note that the allowed direction of movement may be straight, or have a slight arc, depending on the particular design adopted for a given embodiment.

According to various embodiments, the actuator **824** may be a thermal actuator. In such embodiments, placing the coupling closer to the ends of the modules **802**, **804**, **822** may allow for the greatest amount of motion when using the thermal actuator.

In one approach, the actuator **824** comprises a preferably semi-rigid body, e.g., with beams **810**, **820** coupled to opposite ends of each adjacent module pair **802** and **804**, **804** and **822**. The beams **810**, **820** may be constructed of aluminum or other material with a coefficient of thermal expansion suitable for generating the desired expansion and/or contraction thereof. The temperature of all or a portion of the actuator **824** may be adjusted to induce the expansion and/or contraction thereof. One or both of the beams **810**, **820** may be heated via any suitable mechanism, including resistive (Joule) heating of the beams **810**, **820** themselves or of heating elements coupled thereto, raising of an ambient temperature, inductive heating, laser-induced heating, etc., The beams **810**, **820** may be cooled via any suitable mechanism, including by a Peltier device, by reducing or terminating application of heat thereto, etc. When one or both of the beams **810**, **820** may be heated, the thermal expansion creates a force that displaces one module with respect to another, e.g., module **802** relative to module **804** and/or module **822** relative to module **804**, and flexes the springs **812**.

Note that a second actuator of any type known in the art may be provided to tilt the assembly to achieve the desired pitch of the transducers relative to the tape and/or for skew compensation. The extent of the relative movement needed to align the modules **802**, **804**, **822** may be dependent upon a degree of tilting.

In another embodiment, the actuator **824** may be made of piezoelectric material such as PZT, or comprise multiple cells of piezoelectric material. In this case, a voltage is applied to the actuator **824** to create relative motion between the modules. In general, any actuator material know in the art can be used, such as shape memory alloys, bi-metallic strips, piezoelectric materials, etc.

Referring now to FIGS. **9A-9B**, system **900** includes an actuator **918**. Actuator **918** may be positioned on over a plurality of modules, e.g., see first and second outer modules **912**, **914** and an inner module **920** of system **900**. Note that FIGS. **9A-9B** are bottom and side views, respectively, of the modules **912**, **914**, **920** and actuator **918**, e.g., readers and/or writers of the modules **912**, **914**, **920** may reside on an opposite side of the modules **912**, **914**, **920** as that shown in FIG. **9A**.

As depicted in FIGS. **9A** and **9B**, the actuator **918** may include a first hollow frame **922** and a second hollow frame **924**. The first hollow frame **922** may have at least two arms **926**, **928** extending between points of coupling **902**, **930**, which couple the actuator **918** to the first outer module **912** and the inner module **920**. Similarly, the second hollow frame **924** may have at least two arms **904**, **906** extending between points of coupling **908**, **910**, which couple the actuator **918** to the second outer module **914** and the inner module **920**.

The openings in the first and second hollow frames **922**, **924** provide access to the center of the modules **912**, **914**, **920** for attaching a cable. The springs **916** as depicted are "C" shaped pieces attached to the ends of the modules **912**, **914**, **920**, but could have any suitable shape.

As illustrated in FIG. **9B**, heating elements **932** may be placed on each of the arms **926**, **928** of the first frame **922** and/or each of the arms **904**, **906** of the second frame **924**, such that any of the arms **926**, **928**, **904**, **906** can be heated evenly and selectively, e.g., simultaneously in pairs. The actuator **918** in this or any other embodiment can be heated with any number of different techniques, such as passing current through the beam directly, a heating element on the beam, wrapping the beam in current carrying wire, etc. In addition or alternatively, the beam may be cooled using any suitable technique or mechanism, including those listed above.

The effectiveness of this thermal actuator can be increased by selecting a design which minimizes the heat transferred to the modules **912**, **914**, **920**. In such designs, attachment pins or adhesives may be comprised of a thermally insulating material. Likewise, a method of insulating the beam from the modules **912**, **914**, **920**, through use of a thermally insulating material at the attachment points may be used in any of the other embodiments. The insulation minimizes heating of the modules **912**, **914**, **920** and results in a maximal displacement for a given temperature.

FIG. **10** depicts a method **1000** for using an actuator to selectively shift modules of a three module magnetic recording head and thereby enable simultaneous writing by multiple modules of the magnetic recording head, in accordance with one embodiment. As an option, the present method **1000** may be implemented to computer rack systems such as those shown in the other FIGS. described herein. Of course, however, this method **1000** and others presented herein may be used to establish security and selective access for a wide variety of devices and/or purposes which may or may not be related to the illustrative embodiments listed herein. Further, the methods presented herein may be carried out in any desired environment. Moreover, more or less operations than those shown in FIG. **10** may be included in method **1000**, according to various embodiments. It should also be noted that any of the aforementioned features may be used in any of the embodiments described in accordance with the various methods.

Method **1000** may be performed as a tape drive-implemented method in a tape drive. As described in various embodiments elsewhere herein, the tape drive may include at least a first outer module having an array of writers, a second outer module having an array of writers, and an inner module positioned between the outer modules, where the inner module has an array of readers.

Operation **1002** of method **1000** includes shifting at least one of the modules by about one half of a center-to-center pitch of the readers of the inner module.

Operation **1004** of method **1000** includes simultaneously writing a plurality of data tracks on a magnetic recording tape using the outer modules. The data tracks written by a trailing one of the outer modules may be offset in a cross-track direction from the data tracks written by a leading one of the outer modules. As described elsewhere herein, simultaneously writing a plurality of data tracks on a magnetic recording tape using the outer modules may utilize the multiple writer modules for simultaneously writing two times the number of data tracks, as well as allowing read-verification of at least half of the written tracks.

Referring now to FIG. **11**, a side view of modules **1102**, **1104**, **1106** are illustrated positioned in an overwrap configuration of a multi-module head system **1100** in accordance with one embodiment. As an option, the present system **1100** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such system **1100** and others presented herein may be used in various applications and/or in permutations which may or may not be specifically described in the illustrative embodiments listed herein. Further, the system **1100** presented herein may be used in any desired environment.

It should be noted that various components of system **1100** are similar to one or more components of systems **300**, **600** of FIGS. **3**-**5** and **6**A-**7**. Accordingly, one or more components of system **1100** may share common component numbering with one or more components of other systems described elsewhere herein.

FIG. **11** illustrates an embodiment where the modules **1102**, **1104**, **1106** are in an overwrap configuration. Particularly, the tape bearing surfaces **502**, **506** of the outer modules **1102**, **1106** are angled slightly more than the tape **508** when set at the desired wrap angle $\alpha\mathbf{2}$ relative to the second outer module **1106**. In this embodiment, the tape **508** does not pop off of the trailing module **1106**, allowing the trailing module **1106** to be used for writing. A preferred embodiment has shortened closures **1110** that allow closer gap-to-gap separation between the modules.

A 32 channel version of a multi-module head system **1100** may use cables **516** having leads on the same or smaller pitch as current 16 channel piggyback LTO modules, or alternatively the connections on the module may be organ-keyboarded for a 50% reduction in cable span. Over-under, writing pair unshielded cables may be used for the writers, as well as integrated servo readers.

The outer wrap angles $\alpha\mathbf{1}$ may be set in the drive, such as by guides of any type known in the art, such as adjustable rollers, slides, etc. or alternatively by outriggers, which are integral to the head. For example, rollers having an offset axis may be used to set the wrap angles. The offset axis creates an orbital arc of rotation, allowing precise alignment of the wrap angle $\alpha\mathbf{1}$.

To assemble any of the embodiments described above, conventional u-beam assembly can be used. Accordingly, the mass of the resultant head may be maintained or even reduced relative to heads of previous generations. Those skilled in the art, armed with the present teachings, will appreciate that other known methods of manufacturing such heads may be adapted for use in constructing such heads. Moreover, unless otherwise specified, processes and materials of types known in the art may be adapted for use in various embodiments in conformance with the teachings herein, as would become apparent to one skilled in the art upon reading the present disclosure.

As a tape is run over a module, it is preferred that the tape passes sufficiently close to magnetic transducers on the module such that reading and/or writing is efficiently performed, e.g., with a low error rate. According to some approaches, tape tenting may be used to ensure the tape passes sufficiently close to the portion of the module having the magnetic transducers. To better understand this process, FIGS. **12**A-**12**C illustrate the principles of tape tenting. FIG. **12**A shows a module **1200** having an upper tape bearing surface **1202** extending between opposite edges **1204**, **1206**. A stationary tape **1208** is shown wrapping around the edges **1204**, **1206**. As shown, the bending stiffness of the tape **1208** lifts the tape off of the tape bearing surface **1202**. Tape tension tends to flatten the tape profile, as shown in FIG. **12**A. Where tape tension is minimal, the curvature of the tape is more parabolic than shown.

FIG. **12**B depicts the tape **1208** in motion. The leading edge, i.e., the first edge the tape encounters when moving, may serve to skive air from the tape, thereby creating a subambient air pressure between the tape **1208** and the tape bearing surface **1202**. In FIG. **12**B, the leading edge is the left edge and the right edge is the trailing edge when the tape is moving left to right. As a result, atmospheric pressure above the tape urges the tape toward the tape bearing surface **1202**, thereby creating tape tenting proximate each of the edges. The tape bending stiffness resists the effect of the atmospheric pressure, thereby causing the tape tenting proximate both the leading and trailing edges. Modeling predicts that the two tents are very similar in shape.

FIG. **12**C depicts how the subambient pressure urges the tape **1208** toward the tape bearing surface **1202** even when a trailing guide **1210** is positioned above the plane of the tape bearing surface.

It follows that tape tenting may be used to direct the path of a tape as it passes over a module. As previously mentioned, tape tenting may be used to ensure the tape passes sufficiently close to the portion of the module having the magnetic transducers, preferably such that reading and/or writing is efficiently performed, e.g., with a low error rate.

Magnetic tapes may be stored in tape cartridges that are, in turn, stored at storage slots or the like inside a data storage library. The tape cartridges may be stored in the library such that they are accessible for physical retrieval. In addition to magnetic tapes and tape cartridges, data storage libraries may include data storage drives that store data to, and/or retrieve data from, the magnetic tapes. Moreover, tape libraries and the components included therein may implement a file system which enables access to tape and data stored on the tape.

File systems may be used to control how data is stored in, and retrieved from, memory. Thus, a file system may include the processes and data structures that an operating system uses to keep track of files in memory, e.g., the way the files are organized in memory. Linear Tape File System (LTFS) is an exemplary format of a file system that may be implemented in a given library in order to enables access to compliant tapes. It should be appreciated that various embodiments herein can be implemented with a wide range of file system formats, including for example IBM Spectrum

Archive Library Edition (LTFS LE). However, to provide a context, and solely to assist the reader, some of the embodiments below may be described with reference to LTFS which is a type of file system format. This has been done by way of example only, and should not be deemed limiting on the invention defined in the claims.

A tape cartridge may be "loaded" by inserting the cartridge into the tape drive, and the tape cartridge may be "unloaded" by removing the tape cartridge from the tape drive. Once loaded in a tape drive, the tape in the cartridge may be "threaded" through the drive by physically pulling the tape (the magnetic recording portion) from the tape cartridge, and passing it above a magnetic head of a tape drive. Furthermore, the tape may be attached on a take-up reel (e.g., see **121** of FIG. **1**A above) to move the tape over the magnetic head.

Once threaded in the tape drive, the tape in the cartridge may be "mounted" by reading metadata on a tape and bringing the tape into a state where the LTFS is able to use the tape as a constituent component of a file system. Moreover, in order to "unmount" a tape, metadata is preferably first written on the tape (e.g., as an index), after which the tape may be removed from the state where the LTFS is allowed to use the tape as a constituent component of a file system. Finally, to "unthread" the tape, the tape is unattached from the take-up reel and is physically placed back into the inside of a tape cartridge again. The cartridge may remain loaded in the tape drive even after the tape has been unthreaded, e.g., waiting for another read and/or write request. However, in other instances, the tape cartridge may be unloaded from the tape drive upon the tape being unthreaded, e.g., as described above.

Magnetic tape is a sequential access medium. Thus, new data is written to the tape by appending the data at the end of previously written data. It follows that when data is recorded in a tape having only one partition, metadata (e.g., allocation information) is continuously appended to an end of the previously written data as it frequently updates and is accordingly rewritten to tape. As a result, the rearmost information is read when a tape is first mounted in order to access the most recent copy of the metadata corresponding to the tape. However, this introduces a considerable amount of delay in the process of mounting a given tape.

To overcome this delay caused by single partition tape mediums, the LTFS format includes a tape that is divided into two partitions, which include an index partition and a data partition. The index partition may be configured to record metadata (meta information), e.g., such as file allocation information (Index), while the data partition may be configured to record the body of the data, e.g., the data itself.

Looking to FIG. **13**, a magnetic tape **1300** having an index partition **1302** and a data partition **1304** is illustrated according to one embodiment. As shown, data files and indexes are stored on the tape. The LTFS format allows for index information to be recorded in the index partition **1302** at the beginning of tape **1306**, as would be appreciated by one skilled in the art upon reading the present description.

As index information is updated, it preferably overwrites the previous version of the index information, thereby allowing the currently updated index information to be accessible at the beginning of tape in the index partition. According to the specific example illustrated in FIG. **13**, a most recent version of metadata Index 3 is recorded in the index partition **1302** at the beginning of the tape **1306**. Conversely, all three version of metadata Index 1, Index 2, Index 3 as well as data File A, File B, File C, File D are recorded in the data partition **1304** of the tape. Although Index 1 and Index 2 are old (e.g., outdated) indexes, because information is written to tape by appending it to the end of the previously written data as described above, these old indexes Index 1, Index 2 remain stored on the tape **1300** in the data partition **1304** without being overwritten.

The metadata may be updated in the index partition **1302** and/or the data partition **1304** differently depending on the desired embodiment. According to some embodiments, the metadata of the index partition **1302** may be updated in response to the tape being unmounted, e.g., such that the index may be read from the index partition when that tape is mounted again. The metadata may also be written in the data partition **1304** so the tape may be mounted using the metadata recorded in the data partition **1304**, e.g., as a backup option.

According to one example, which is no way intended to limit the invention, LTFS LE may be used to provide the functionality of writing an index in the data partition when a user explicitly instructs the system to do so, or at a time designated by a predetermined period which may be set by the user, e.g., such that data loss in the event of sudden power stoppage can be mitigated.

The present invention may be a system, a method, and/or a computer program product. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a ROM, an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

Moreover, a system according to various embodiments may include a processor and logic integrated with and/or executable by the processor, the logic being configured to perform one or more of the process steps recited herein. By integrated with, what is meant is that the processor has logic embedded therewith as hardware logic, such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), etc. By executable by the processor, what is meant is that the logic is hardware logic; software logic such as firmware, part of an operating system, part of an application program; etc., or some combination of hardware and software logic that is accessible by the processor and configured to cause the processor to perform some functionality upon execution by the processor. Software logic may be stored on local and/or remote memory of any memory type, as known in the art. Any processor known in the art may be used, such as a software processor module and/or a hardware processor such as an ASIC, a FPGA, a central processing unit (CPU), an integrated circuit (IC), etc.

It will be clear that the various features of the foregoing systems and/or methodologies may be combined in any way, creating a plurality of combinations from the descriptions presented above.

It will be further appreciated that embodiments of the present invention may be provided in the form of a service deployed on behalf of a customer.

The inventive concepts disclosed herein have been presented by way of example to illustrate the myriad features thereof in a plurality of illustrative scenarios, embodiments, and/or implementations. It should be appreciated that the concepts generally disclosed are to be considered as modular, and may be implemented in any combination, permutation, or synthesis thereof. In addition, any modification, alteration, or equivalent of the presently disclosed features, functions, and concepts that would be appreciated by a person having ordinary skill in the art upon reading the instant descriptions should also be considered within the scope of this disclosure.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of an embodiment of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. An apparatus, comprising:

a first outer module having an array of writers;

a second outer module having an array of writers;

an inner module positioned between the outer modules, the inner module having an array of readers; and a first actuator for shifting the first outer module, relative to the inner module, in a cross-track direction by about one half of a center-to-center pitch of the writers of the first outer module for selectively aligning and misaligning the writers of the first outer module with the readers of the inner module along a tape travel direction; and

a controller electrically coupled to the readers and writers, the controller being configured to cause the writers of both outer modules to simultaneously write a plurality of data tracks on a magnetic recording tape.

2. An apparatus as recited in claim **1**, comprising a second actuator for shifting the second outer module, relative to the inner module, by about one half of a center-to-center pitch of the writers of the second outer module for selectively aligning and misaligning the writers of the second outer module with the readers of the inner module along a tape travel direction.

3. An apparatus as recited in claim **1**, comprising a skew compensation actuator for rotating the modules to compensate for tape skew.

4. An apparatus as recited in claim **1**, further comprising:

a drive mechanism for passing a magnetic medium over the modules.

5. An apparatus as recited in claim **1**, wherein the controller is configured to read-verify tracks written by the second outer module using signals from the readers of the inner module.

6. An apparatus as recited in claim **5**, wherein the controller is configured to cause the writers of the first outer module to be offset in the cross-track direction from the readers of the inner module by about one half of the center-to-center pitch of the writers of the first outer module when read-verifying the tracks written by the second outer module.

7. An apparatus, comprising:

a first outer module having an array of writers;

a second outer module having an array of writers, the writers of the second outer module being offset from the writers of the first outer module in a cross-track direction by about one half of a center-to-center pitch of the writers of the second outer module, positions of the first and second outer modules being fixed relative to one another;

an inner module positioned between the outer modules, the inner module having an array of readers; and

an actuator for shifting the inner module, relative to the outer modules, for selectively aligning the readers with the writers of the outer modules depending on tape travel direction.

8. An apparatus as recited in claim **7**, comprising a skew compensation actuator for rotating the modules to compensate for tape skew.

9. An apparatus as recited in claim **7**, further comprising:

a drive mechanism for passing a magnetic medium over the modules; and

a controller electrically coupled to the readers and writers.

10. An apparatus as recited in claim **9**, wherein the controller is configured to read-verify tracks written by a leading one of the modules using signals from the readers of the inner module.

11. A tape drive-implemented method in a tape drive having at least a first outer module having an array of writers, a second outer module having an array of writers, and an inner module positioned between the outer modules, the inner module having an array of readers, the method comprising:

shifting at least one of the modules by about one half of a center-to-center pitch of the readers of the inner module; and

simultaneously writing a plurality of data tracks on a magnetic recording tape using the outer modules, wherein the data tracks written by a trailing one of the outer modules are offset in a cross-track direction from the data tracks written by a leading one of the outer modules.

12. A method as recited in claim **11**, wherein the positions of the first and second outer modules are fixed relative to one another.

13. A method as recited in claim **11**, comprising shifting the second outer module, relative to the inner module, by about one half of a center-to-center pitch of the writers of the second outer module.

14. A method as recited in claim **11**, comprising shifting the inner module, relative to the outer modules, for selectively aligning the readers with the writers of the outer modules depending on tape travel direction.

15. A method as recited in claim **11**, comprising rotating the modules to compensate for tape skew.

16. A method as recited in claim **11**, comprising, during the writing, read-verifying the data tracks written by the leading one of the outer modules using the readers of the inner module.

17. A method as recited in claim **16**, where the data tracks written by the trailing one of the outer modules is not read-verified.

18. A method as recited in claim **16**, comprising read-verifying the data tracks written by the trailing one of the outer modules in a second pass of the magnetic recording tape over the modules.

19. A method as recited in claim **16**, comprising shifting the inner module relative to the outer modules for selectively aligning the readers of the inner module with the writers of one of the outer modules depending on tape travel direction.

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